# AI-Powered USB Handbook

## USB

*AI-Powered USB Handbook Team*

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# 1. AI-Powered USB Handbook


## 1.1 USB !

AI-Powered USB Handbook USB , AI ,

**USB 3.2 Gen 2x2** , **Thunderbolt 4** **Type-C** , ,

## 1.2 ✨

### 1.2.1 📚

- **4500+**
- **74+**
- **34** Mermaid
- **4**
- **46+** FAQ

### 1.2.2 🎯

- ✅ :
- ✅ :
- ✅ :
- ✅ :

### 1.2.3 🔬

- 🔹 USB 1.0 USB4
- 🔹 Thunderbolt 1-5
- 🔹 USB PD
- 🔹

## 1.3 📑

### 1.3.1 1

### 1.3.2 2 USB

📊 **800+ | 18+ | |**

Type-A Type-C USB :

: - 🔌 USB Type-A/B/C 📍 - Type-C 2📜 - Mini/Micro🎬USB - A💰t M🖼️le - -

: - USB - Type-C - vs Type-C - FAQ(12 )

📖 2

---

### 1.3.3 3 :USB

**⚡ 900+ | 15+ | 2 | 8**

USB :

: - 📅 USB 2.0 → USB4 🔀 - USB 3.🔬x - (8b/🌐0b vs 128⏱️132b) - USB4 - ( 10GB ) -🔽

: - USB - USB 3.2 Gen 2x2 - USB 4 - (U )

📖 3

---

### 1.3.4 4 Thunderbolt

**⛈️ 1200+ | 18+ | 2 | 5**

:

: - 📜 Thunderbolt 1-5 🔬 - 📊 - 🔗B3/TB4/TB5 🎮 (Daisy Chain) - eGPU - Thunderbolt vs USB4

: 1. 🎬 🎮 2. +🎵eGPU📷 3. 4.

📖 4

---

### 1.3.5 5

**🔋 800+ | 20+ |**

USB :

: - ⚡ USB PD 📱 - 🔌 PPS - - Quick Charge(QC 1.0-5) - OPPO VOOC/SuperVOOC - FCP/ SCP - - Pump🔍Express - P✅Ma📈er - -

: - - vs - / -

📖 5

---

### 1.3.6 6

**❓ 800+ | 20+ FAQ | 7 | 3**

:

**5** : 1. 🔌 ⚡6 ) 2. 🔋 (⛈️ ) 3. (4 ) 4🔭 Thunderbolt (3 ) 5. (3 )

: - ❌ Type-C = ❌ - USB❌ 3.0 - ❌Thunderbolt 3 - - - PD " " - ❌ Thunderbolt 4 Thunderbolt 3

: - 📊 USB 🔋 - U🔀 🔧 - -

📖 6

## 1.4 📊

### 1.4.1

| | | | | FAQ | |
|---|---|---|---|---|---|
| 2 | 800+ | 18+ | 7 | 12 | Alt Mode |
| 3 | 900+ | 15+ | 10 | 7 | |
| 4 | 1200+ | 18+ | 7 | 7 | Thunderbolt eGPU |
| 5 | 800+ | 20+ | 8 | - | PD |
| 6 | 800+ | 3 | 2 | 20+ | FAQ |
| | **4500+** | **74+** | **34** | **46+** | - |

### 1.4.2

** ** - USB Type-A/B/C - Mini/Micro USB - Thunderbolt - ** ** - USB PD 2.0/3.0/3.1 - PPS - - E-Marker ** ** - USB 1.0 → USB4 - Thunderbolt 1 → 5 - - - eGPU - -

## 1.5 🎯

| | | |
|---|---|---|
| 🖥️ | USB | 2 3 4 |
| 💼 | | 4 6 |
| 🎓 | USB | |
| 🛒 | , | 6 + |
| 👩‍💻 | USB | 2 3 5 |
| 📹 | | 4 |

## 1.6 🌟

### 1.6.1

```
graph LR
    A[  ] --> B[ 2 \u003cbr\u003e    ]
    B --> C[ 6 \u003cbr\u003eFAQ]
    C --> D[     ]

    style A fill:#e1f5ff
    style B fill:#e1ffe1
```

```
    style C fill:#fffacd
    style D fill:#ffe1e1
```

1. 📌 2 ,
2. ❓ 6 FAQ,
3. 📊 ,

### 1.6.2

```
graph LR
    A[  ] --> B[ 3 \u003cbr\u003e    ]
    B --> C[ 4 \u003cbr\u003eThunderbolt]
    C --> D[ 5 \u003cbr\u003e    ]
    D --> E[    ]

    style A fill:#ffe1ff
    style B fill:#e1ffe1
    style C fill:#ffe1e1
    style D fill:#e1f5ff
    style E fill:#fff4e1
```

1. ⚡ 3 ,
2. ⛈️ 4 ,
3. 🔋 5 ,
4. 💼 ,

### 1.6.3

1. 🎯 ( )
2. 📖 " "
3. 📊
4. ⚠️ 6 " ",
5. ✅

---

## 1.7 💡

### 1.7.1 1.

**15** **Mermaid** :📅 🔄 🌳 - 📊 - -

### 1.7.2 2.

**3** : - ⚡ USB ( 1🔋GB ) -🔀 USB - (6×6)

### 1.7.3 3.

**2** : - 🔧 USB 🔋8 ) - (6 )

### 1.7.4 4.

**7** 🎬 - 🎮 - 🎵 📷 eGPU - -

---

## 1.8 📚

### 1.8.1

- 
- 
- 

### 1.8.2

-  (USB-IF  Intel)
- 
- 

### 1.8.3

-  (Thunderbolt 5  USB4 v2)
- 
- 

---

## 1.9 🔗

### 1.9.1

- 📘 USB-IF
- ⚡ Thunderbolt Technology
- 🔋 USB Power Delivery

### 1.9.2

- ✅ USB-IF
- ✅ Thunderbolt

### 1.9.3

- 🔬 CrystalDiskMark -  ( )
- ⚡ POWER-Z KT002 -  (¥300-500)
- 📊 USB Device Tree Viewer -  ( )

---

## 1.10 🙏

 !

AI , ,

---

## 1.11 📞

?

- 💬 GitHub Discussions -
- 🐛 GitHub Issues -
- 🤝 Pull Requests -

---

**📚 USB !** Mad❤️with by the community | Powered🏠y AI [ ](../READ📖IE.md) ⭐ ](# ) · [ Star on GitHub](https://github.com/codetilldie/ai-powered-usb-handbook)

# 2.  1  (Introduction)

## 2.1

USB (Universal Serial Bus)  USB  USB 3.2 Gen 2x2  Type-C

**AI-Powered USB Handbook**  USB  AI

## 2.2

- 
- 4  USB4
- USB

## 2.3

1. 
2.  USB 1.0  USB4
3.  Intel  Thunderbolt  USB
4.  USB PD  PPS
5. 

# 3.  2  :USB  (USB Connector Types)

USB

## 3.1 USB

### 3.1.1

USB  1996  Type-A  Type-B

- MP3
-
-
-

[!IMPORTANT] 2024  **USB Type-C**  iPhone 15  Type-C

### 3.1.2 USB

```
timeline
    title USB
    1996 : USB 1.0    : Type-A / Type-B :      1.5Mbps (  )
    1998 : USB 1.1 :     12Mbps (  )
    2000 : USB 2.0 : 480Mbps (  ) : Type-A/B
    2000 : Mini USB    : Mini-A / Mini-B :
    2007 : Micro USB    : Micro-A / Micro-B :       <br>          Mini USB
    2008 : USB 3.0    : 5Gbps (   ) : Type-A/B     <br>
    2013 : Micro USB 3.0 :        :
    2014 : USB Type-C    :     <br>      :
    2017 : USB 3.2 : 20Gbps : Type-C
    2019 : USB4 : 40Gbps :     Type-C
    2024 :      Type-C :
```

### 3.1.3

**Type-A**  -  Type-A  1996  -  -  USB 3.2  Type-A

**Micro USB**  - 2007-2020  -  Micro USB -  Type-C

**Type-C**  - 2014  Lightning  - 2024  -

## 3.2 USB Type-A

USB

-
-  12mm × 4.5mm
-  1,500

## 3.2.1

**USB 2.0 Type-A 4**

| | | |
|---|---|---|
| 1 | VBUS | (+5V) |
| 2 | D- | |
| 3 | D+ | |
| 4 | GND | |

**USB 3.0/3.1/3.2 Type-A 9**

USB 2.0 4 5

| | |
|---|---|
| 5 | StdA_SSRX- |
| 6 | StdA_SSRX+ |
| 7 | GND_DRAIN |
| 8 | StdA_SSTX- |
| 9 | StdA_SSTX+ |

[!NOTE] USB 3.0+ 5 USB 2.0 4 USB 3.0 USB 2.0 4

## 3.2.2

USB-IF

| | | |
|---|---|---|
| / | USB 2.0 | 480Mbps |
| | USB 3.0/3.1 Gen 1 | 5Gbps |
| **Teal** | USB 3.1 Gen 2 | 10Gbps |
| | USB 3.2 / | 20Gbps |
| | / | BC 1.2 |

[!TIP] USB 3.0+ / USB 2.0

## 3.2.3

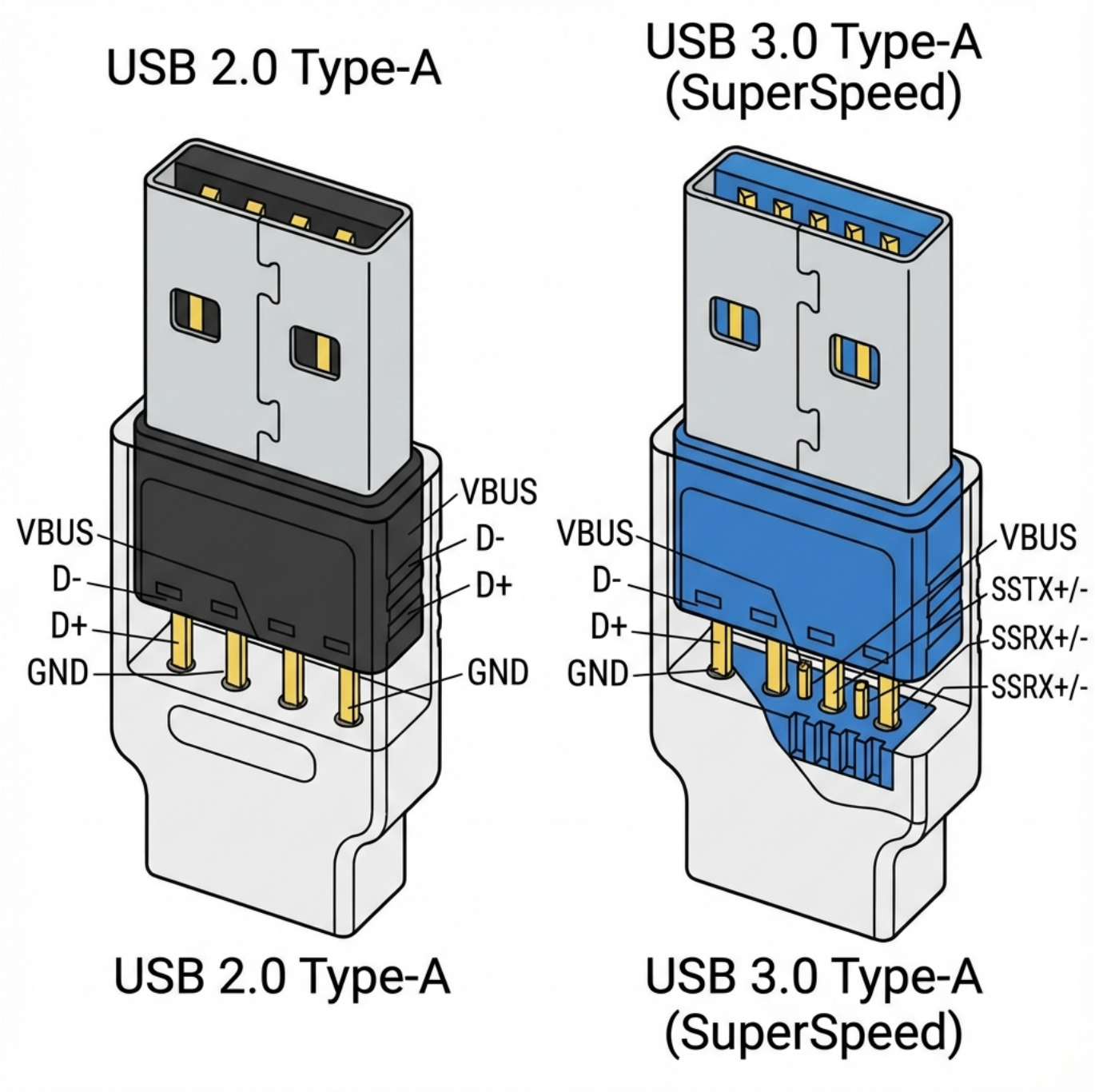
| USB | | | |
|---|---|---|---|
| USB 2.0 | 500mA | 2.5W (5V 0.5A) | |
| USB 3.0 | 900mA | 4.5W (5V 0.9A) | |
| USB BC 1.2 | 1.5A | 7.5W (5V 1.5A) | (DCP) |
| USB 3.1/3.2 | 3A | 15W (5V 3A) | |

[!WARNING] Type-A USB PD >15W **Type-C**

## 3.2.4

-💻 🖥️ 🔌 -🚗 - - USB

- Type-A Type-B Micro USB Type-C




## 3.3 USB Type-B

Type-B Type-A Type-B

### 3.3.1 Type-B

**Standard-B**

- 
- 8mm × 7mm
- 4 USB 2.0 9 USB 3.0
- 

#### Mini USB Type-B

- Standard-B
- 7mm × 3mm
- 5
- MP3 GPS
- Micro USB

#### Micro USB Type-B

-
- 7mm × 1.8mm
- 5 USB 2.0
- 2007-2020
- Type-C

#### Micro USB 3.0 Type-B

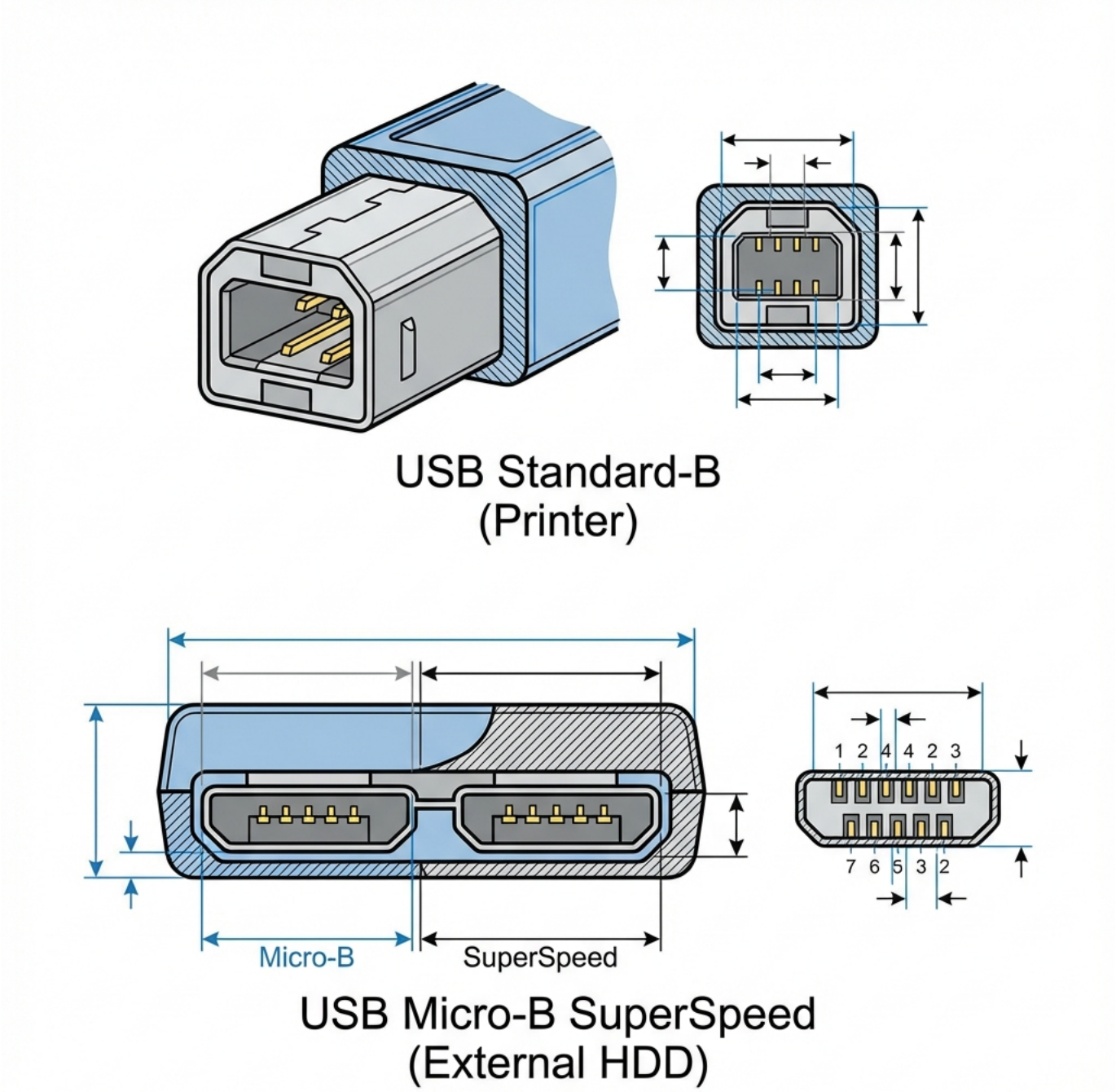
- Micro USB 2.0
- 12mm × 1.8mm
- 10 5 USB 2.0 + 5 USB 3.0
- Elements Backup Plus Galaxy Note 3/S5
- Micro USB 2.0

```
graph LR
    A[Standard-B<br/>  <br/>   ]
    B[Mini-B<br/>  <br/>MP3/  ]
    C[Micro-B<br/>   <br/>    ]
    D[Micro-B 3.0<br/>  <br/>    ]

    A -->|   | B
    B -->|  | C
    C -->|  | D

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#ffe1e1
```

---

## 3.3.2 Type-B

- Type-B USB " " Type-B Type-A
- Standard-B
- **Type-C** Type-C




## 3.4 Mini USB & Micro USB

### 3.4.1 Mini USB

- 2000
- Standard-B
- 5

- 
- **Mini-A**
- **Mini-B**
- **Mini-AB** OTG
- MP3 GPS
- **2007** **Micro USB**

## 3.4.2 Micro USB

### Micro USB 2.0 Type-B

5

| | | |
|---|---|---|
| 1 | VBUS | (+5V) |
| 2 | D- | |
| 3 | D+ | |
| 4 | ID | OTG |
| 5 | GND | |

- **ID** **OTG (On-The-Go)** - ID U - ID - 7mm × 1.8mm Mini USB - 10,000

### OTG (On-The-Go)

OTG

-📱 🎮 ⌨️ -📷 - / -

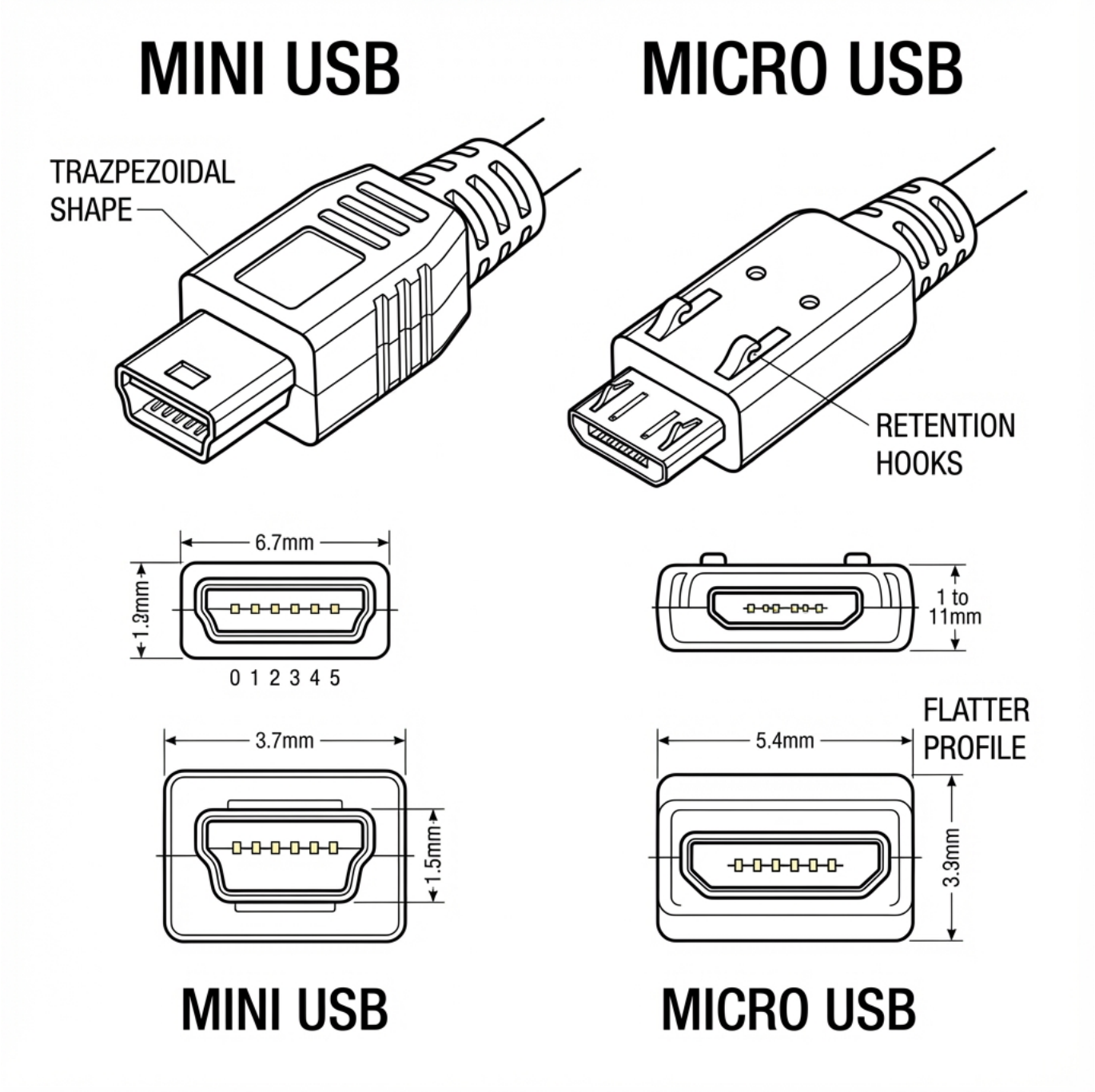
- **Micro USB OTG** Micro USB Type-A - ID - OTG

## 3.4.3 Micro USB

Micro USB

1. - ❌ ❌ ❌ -
2. - 10,000 -
3. - Micro USB **USB 2.0** 480Mbps - 4K - Micro USB 3.0 5Gbps
4. - 7.5W (5V 1.5A, BC 1.2) - 30W+
5. - - Alt Mode

[!WARNING] Micro USB - - -




## 3.5 USB Type-C

- 
- 8.4mm × 2.6mm
- 10,000 Micro USB
- 2014

[!IMPORTANT] **Type-C** Type-C USB 2.0 4 (40Gbps)

### 3.5.1 Type-C

1. ✅
2. ✅ + + +
3. ✅ 240W (USB PD 3.1)
4. ✅ 40Gbps (USB4 / Thunderbolt 4)
5. ✅
6. ✅

---

### 3.5.2 Type-C 24

Type-C **24**

```
   12
A1 GND  | A2 TX1+ | A3 TX1- | A4 VBUS | A5 CC1  | A6 D+  | A7 D-  | A8 SBU1 | A9 VBUS | A10 RX2- | A11 RX2+ | A12 GND
═══════════════════════════════════════════════════════════════════════════════════════════════════════════════
   12
B12 GND | B11 RX1+ | B10 RX1- | B9 VBUS | B8 SBU2 | B7 D-  | B6 D+  | B5 CC2  | B4 VBUS | B3 TX2- | B2 TX2+ | B1 GND
```

| | | | | |
|---|---|---|---|---|
| | 8 | VBUS (A4, A9, B4, B9)<br>GND (A1, A12, B1, B12) | | 240W |
| **USB 2.0** | 4 | D+ (A6, B6)<br>D- (A7, B7) | USB 2.0 | 480Mbps |
| **USB 3.x/4** | 8 | TX1+/- (A2, A3)<br>RX1+/- (B10, B11)<br>TX2+/- (B2, B3)<br>RX2+/- (A10, A11) | | TX/RX 5-40Gbps |
| | 2 | CC1 (A5)<br>CC2 (B5) | | PD |
| | 2 | SBU1 (A8)<br>SBU2 (B8) | Alt Mode | |

[!NOTE] Type-C

---

## 3.5.3 CC

### CC

**CC (Configuration Channel)** Type-C

1.
2. CC1 CC2
3. " "
4. **(DRP: Dual-Role Power)**
5. **Source** **Sink**
6. Type-C
7.
8. Source CC
9. **Default (500mA/900mA) 1.5A 3A**
10. **USB PD**
11.
12. PD Source_Capabilities Request

```
graph LR
    A[   Type-C   ] --> B{   CC1/CC2}
    B -->|CC1    | C[       <br/>A2-A11]
    B -->|CC2    | D[       <br/>B2-B11]
    C --> E[    ]
    D --> E

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#e1ffe1
    style E fill:#ffe1f5
```

## 3.5.4 Alt Mode Type-C

**Alternate Mode ( )** Type-C **USB**

### Alt Mode

**1. DisplayPort Alt Mode** - Type-C - - - / - Type-C HDMI/DP - 8K@60Hz DP 2.0 - USB 3.x TX/RX

**2. Thunderbolt 3/4 Alt Mode** - PCIe DisplayPort USB - 40Gbps - - (eGPU) - SSD - - Thunderbolt 3/4 Type-C

**3. HDMI Alt Mode** - HDMI - Type-C HDMI

**4. Audio Adapter Accessory Mode** - - Type-C 3.5mm - SBU1/SBU2

### Alt Mode

```
graph TB
    A[Type-C   ] --> B{   Alt Mode}
    B -->|USB   | C[   USB   <br/>    ]
    B -->|DP Alt Mode| D[   DP   <br/>    ]
    B -->|Thunderbolt Mode| E[      <br/>PCIe+DP+USB]

    D --> F[TX/RX   <br/>      ]
    E --> G[     <br/>40Gbps   ]
```

```
    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#ffe1e1
    style E fill:#ffe1ff
```

[!TIP] Type-C Alt Mode " " "DP Alt Mode"

---

## 3.5.5 Type-C vs Type-C

Type-C " "

| | USB 2.0 | USB 3.x | Type-C | Thunderbolt 4 |
|---|---|---|---|---|
| | 480Mbps | 5-20Gbps | 5-40Gbps | 40Gbps |
| | 15W | 100W | 240W (PD 3.1) | 100W |
| | ❌ | ❌ | ✅ (DP Alt Mode) | ✅ (DP 2.0) |
| | ❌ | ❌ | ❌ | ✅ |
| | 💰 | 💰💰 | 💰💰💰 | 💰💰💰💰 |
| | | /PC | / | /Mac |

" "

- **USB 2.0** **Type-C** iPhone 15 - USB 3.x PHY - $1-2 - 480Mbps - **Type-C** - DP Mux -

[!WARNING] Type-C - 💻 DeX - Type-C - USB PD

---

## 3.5.6 Type-C Thunderbolt

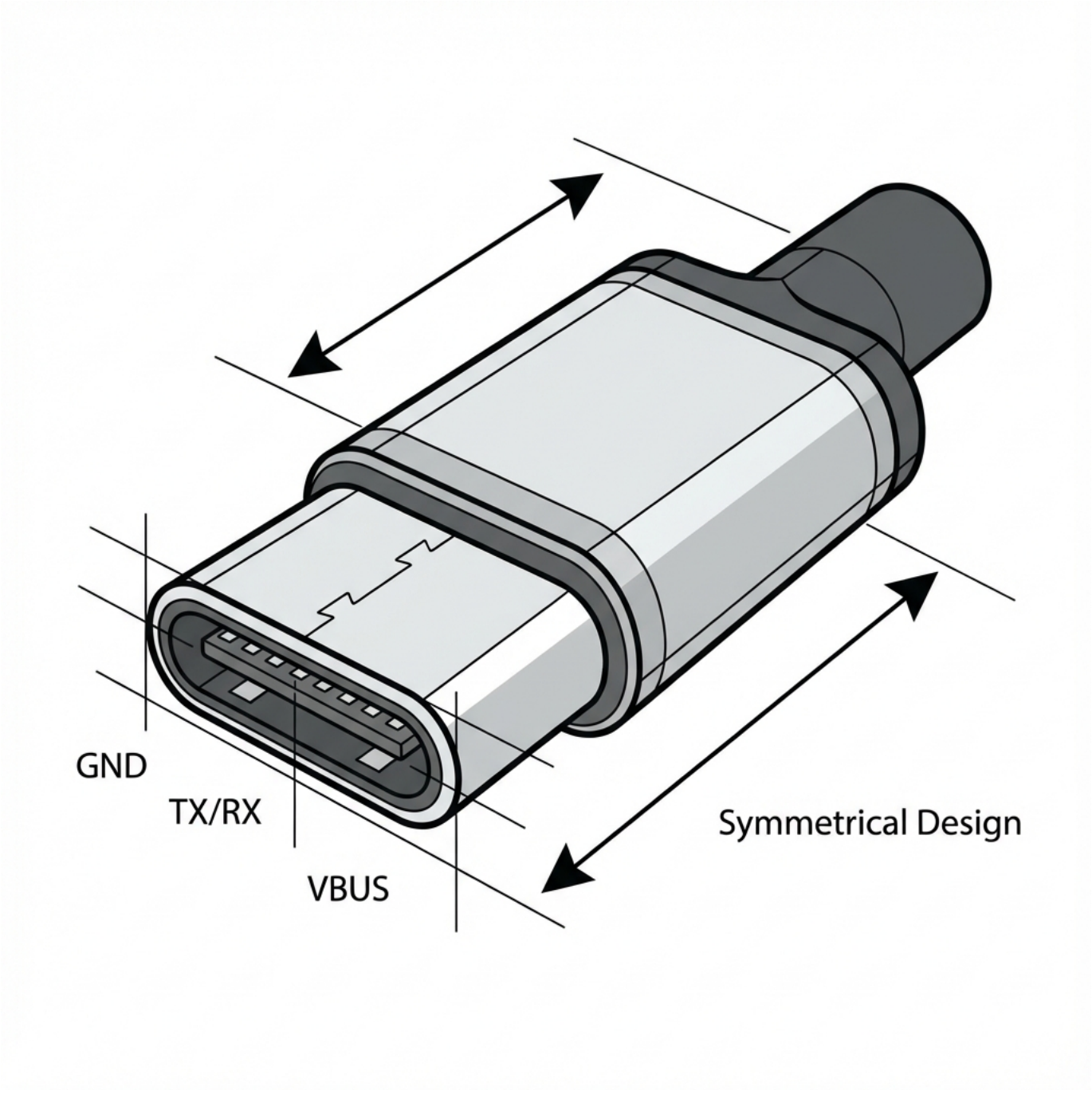
**Thunderbolt 3/4** **Type-C** **Type-C ≠ Thunderbolt**

| USB Type-C | Thunderbolt 3/4 |
|---|---|
| | |
| USB2.0~USB4 (480Mbps-40Gbps) | 40Gbps |
| + | + + +PCIe |
| USB-IF | Intel |
| USB | ⚡ |
| | |

**Thunderbolt**

-⚡ 🔢 - Thunderbolt 3/4 "3" 💻" - MacBook Thunderbolt

- eGPU - 40Gbps - Daisy Chain



# 3.6 USB

## 3.6.1

| | (mm) | | | | |
|---|---|---|---|---|---|
| **Type-A** | 12×4.5 | 4/9 | 20Gbps (USB 3.2) | 15W | 1,500 |
| **Standard-B** | 8×7 | 4/9 | 20Gbps | | 1,500 |
| **Mini USB** | 7×3 | 5 | 480Mbps | 2.5W | 5,000 |
| **Micro USB** | 7×1.8 | 5 | 480Mbps | 7.5W | 10,000 |
| **Micro USB 3.0** | 12×1.8 | 10 | 5Gbps | 7.5W | 10,000 |
| **Type-C** | 8.4×2.6 | 24 | 40Gbps (USB4) | 240W (PD 3.1) | 10,000 |

[!TIP] " " " "

# 3.7

## 3.7.1 USB

**1.** - **Type-A** - **Type-C** - **Micro USB**

**2.** **Type-A** - 🔵 USB 3.0/3.1 Gen 1 (5Gbps) / USB 2.0 (480Mbps) - 🟡 USB 3.2 -

**3.** - **SS (SuperSpeed)** USB 3.0 (5Gbps) - **SS 10** **SS+** USB 3.1 Gen 2 (10Gbps) - **SS 20** USB 3.2 (20Gbps) - ⚡ Thunderbolt 3/4 (40Gbps) - **USB-IF**

**Type-C** ❌ ⚠️ - **USB 2.0** USB 2.0 480Mbps - **USB 3.x** ✅ - **E-Marker** 100W ✅5A - **Thunderbolt** 40Gbps + 100W

1. SS 5A Thunderbolt 2. USB POWER-Z 3.

## 3.7.2 FAQ

**Q1:** **Type-C** - **A**: Charge-Only Cable " "

**Q2: Type-C** **Type-A** - **A**: - Type-A USB 3.2: 20Gbps - Type-A 15W USB PD - Type-C Alt Mode

**Q3:** **Type-C** - **A**: - " " "DP Alt Mode" - " USB PD" - "USB 3.x/4" -

**Q4: Micro USB OTG** **U** - **A**: OTG **ID** " " U Micro USB ID

**Q5: Type-C** - **A**: - 💰 10 💰💰 USB 2.0 - 💰💰💰 USB 3.x + - 100+ +E-Marker+USB-IF 💰💰💰💰 200+ Thunderbolt 40Gbps

**Q6:** **Type-C** **PD** - **A**: 1. USB PD 2. USB PD 3. 3A 5A E-Marker 4.

## 3.8

### 3.8.1

**USB** -✅ USB 3.0 USB 2.0 ✅480Mbps - USB 3✅ USB 2.0 - Type-C Type-A - ❌

### 3.8.2

| | | | | |
|---|---|---|---|---|
| **Type-C to Type-A** | Type-A | 15W | ❌ | |
| **Type-C to HDMI/DP** | N/A | | ✅ | DP Alt Mode |
| **Micro USB to Type-C** | USB 2.0 (480Mbps) | 7.5W | ❌ | |
| **Thunderbolt to Type-C** | 40Gbps | 100W | ✅ | |

[!WARNING] - - -

### 3.8.3

1. - ❌Micro USB ⚠️ ✅ Type-A - Type-C
2. - ﷺ 💨 - 🌾24 - ⚠️ -
3. - **Micro USB** - **Type-C** -**Type-A**
4. - - - >45°C

## 3.9

### 3.9.1

**Type-C**

**1** - - 30W 3A 20 - 67W-100W E-Marker 5A 40-80 - 100W EPR 100+ - Anker Baseus UGREEN Apple

**2** - - USB 2.0 10-20 - / USB 3.2 30-60 - Thunderbolt 4 200+ - - 1 - 1-2 - 3

**3** - Type-C to HDMI/DP 4K@60Hz - 2 - Belkin Cable Matters Club 3D

-✅ **USB-IF** usb.org ✅ **Thunderbolt** ⚠️ -

### 3.9.2

- 2× Type-A (USB 3.0) - 1× Type-C (USB 3.1 + PD ) - 1× HDMI

- 2× Type-A (1 USB 3.2) - 2× Type-C (1 PD + DP Alt Mode) - 1× HDMI / DP

/ - 1× Type-A (USB 3.2) - 3× Type-C ( 2 Thunderbolt 4) - 4K - 100W PD

**1** / - GaN 30-67W - PD + PPS - Anker Baseus

**2** - GaN 100-150W - 2C1A 3C - - Anker 747 (150W) Baseus 160W

**3** **+** - 100W+ - 65W - GaN

## 3.10

| | | |
|---|---|---|
| | Reversible Plug | Type-C |
| **Alt Mode** | Alternate Mode | Type-C USB / |
| **OTG** | On-The-Go | U |
| **CC** | Configuration Channel | Type-C PD |
| **SBU** | Sideband Use | Type-C Alt Mode |
| **DRP** | Dual-Role Power | Type-C |
| **E-Marker** | Electronically Marked Cable | |
| **GaN** | Gallium Nitride | |
| **eGPU** | External Graphics Processing Unit | Thunderbolt |
| **Daisy Chain** | | Thunderbolt 6 |
| **PHY** | Physical Layer Chip | |
| **DP Mux** | DisplayPort Multiplexer | Alt Mode |

## 3.11

### 3.11.1

- USB-IF
- USB Type-C
- Thunderbolt

### 3.11.2

- USB-IF
-

### 3.11.3

- **POWER-Z** USB
- **ChargerLAB KT002**
- **USB Device Tree Viewer** USB Windows

• **System Information** Mac USB/Thunderbolt

---

[!NOTE] USB USB4 Version 2.0 (80Gbps) PD USB-IF

# 4. 3 USB (USB Transfer Protocols)

USB , USB-IF (USB ) , , USB

## 4.1 USB ?

USB , :

- : U 20 , 200 ?
- : Type-C , 100 ?
- :"USB 3.2 Gen 2x2" ?
- : " " , ?

:

- 📱 (20GB):
- USB 2.0 U : **10**
- USB 3.2 Gen 2 U : **30**
- 🎬 **4K** (100GB):
- USB 2.0 : **50**
- USB4 SSD: **30**

, USB ,

[!IMPORTANT] **USB ≠ USB** Type-C USB 2.0 (480Mbps), USB4(40Gbps)

## 4.2 USB

```
timeline
    title USB
    1996 : USB 1.0    : Low Speed 1.5Mbps :
    1998 : USB 1.1 : Full Speed 12Mbps :
    2000 : USB 2.0    : High Speed 480Mbps :      10+
    2008 : USB 3.0    : SuperSpeed 5Gbps :       \u003cbr\u003e     10
    2013 :        : USB 3.0 → USB 3.1 Gen 1 :
    2017 : USB 3.1 Gen 2 : 10Gbps :
    2017 : USB 3.2    : 20Gbps :    Type-C
    2019 :       : USB 3.x      :
    2019 : USB4    :    Thunderbolt 3 : 40Gbps
    2021 : USB4 v2.0 : 80Gbps/120Gbps :
```

## 4.3 USB

### 4.3.1 USB 1.0 / 1.1 (1996-2000)

- **Low Speed**: 1.5 Mbps
- :
- : ,
- **Full Speed**: 12 Mbps
- :
- : " ",

### 4.3.2 USB 2.0 (2000)

- **High Speed**: **480 Mbps** ( 60 MB/s)
- : 30-40 MB/s
- :
- 📱 " "
- 📱 ( iPhone 15 )
- 🖱️
- ⌨️ USB
- : ,

[!NOTE] USB 2.0 **20+** , , : - ( ) - -

---

## 4.4 USB 3.x

USB-IF 2013 2019 , ,

### 4.4.1 ?

**USB-IF** : - " , " - " " - " "

: - ❌ ❌ ❌ - - ,

[!WARNING] USB-IF " " ,

---

### 4.4.2

, USB 3.x :

| ( ) | (2013) | (2019, ) | | | | |
|---|---|---|---|---|---|---|
| **USB 3.0** | USB 3.1 Gen 1 | **USB 3.2 Gen 1** | USB 3.0 / 5Gbps | 5 Gbps | ~450 MB/s | 8b/10 |
| N/A | **USB 3.1 Gen 2** | **USB 3.2 Gen 2** | USB 3.1 / 10Gbps | 10 Gbps | ~900 MB/s | 128b/ |
| N/A | N/A | **USB 3.2 Gen 2x2** | USB 3.2 / 20Gbps | 20 Gbps | ~1.8 GB/s | 128b/ |

[!TIP] : , : - 🔵 **SS 5Gbps** = USB 3.0 ( 🔵 ) - **SS 10 10Gbps** = USB 3.1 Gen 2 ( 🔵 ) - **SS 20 20Gbps** = USB 3.2 Gen 2x2 ( )

---

### 4.4.3

" "

**?**

USB , 0 1, , : - : - : - :

,

#### 8b/10b (USB 3.0)

- : 8 10
- : 8/10 = **80%**
- :
- 5 Gbps
- : 5 × 0.8 = **4 Gbps** ( 500 MB/s)
- , **450 MB/s**

```
graph LR
    A[    \u003cbr\u003e8 bit] -->|  | B[    \u003cbr\u003e10 bit]
    B -->|    | C[5 Gbps]
    C -->|    | D[4 Gbps\u003cbr\u003e80%]

    style A fill:#e1ffe1
    style B fill:#ffe1e1
    style C fill:#fff4e1
    style D fill:#e1f5ff
```

#### 128b/132b (USB 3.1/3.2)

- : 128 132
- : 128/132 = **97%**
- :
- 10 Gbps
- : 10 × 0.97 = **9.7 Gbps** ( 1.2 GB/s)
- , **900 MB/s**

:

| | | **10 Gbps** | |
|---|---|---|---|
| 8b/10b | 80% | 8 Gbps | |
| 128b/132b | 97% | 9.7 Gbps | +21% |

[!NOTE] USB 3.1 128b/132b , ,

---

## 4.4.4 USB 3.2 Gen 2x2

**"2x2"** :

- **2x**: (Dual-Lane)
- **Gen 2**: USB 3.1 Gen 2 (10 Gbps/ )
- : 10 Gbps × 2 = **20 Gbps**

:

Type-C **4** (TX1/RX1 TX2/RX2): - **USB 3.x**: ( ) - **USB 3.2 Gen 2x2**: ( )

```
graph TB
    A[USB 3.2 Gen 2x2   ] --> B[Type-C   ]

    B --> C[   1\u003cbr\u003eTX1/RX1]
    B --> D[   2\u003cbr\u003eTX2/RX2]

    C --> E[10 Gbps]
    D --> F[10 Gbps]

    E --> G[   \u003cbr\u003e20 Gbps]
    F --> G
```

```
    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#e1ffe1
    style G fill:#ffe1f5
```

[!IMPORTANT] USB 3.2 Gen 2x2 **Type-C** , Type-C Type-A 20 Gbps

## 4.5 USB4

USB4 Intel **Thunderbolt 3** , ,

### 4.5.1

- **USB4 Gen 2x2**: 20 Gbps ( )
- **USB4 Gen 3x2**: 40 Gbps ( )
- : **Type-C**, Type-A

### 4.5.2

#### 1. (Tunneling Protocol)

USB4 , :

- **USB 3.2**
- **DisplayPort**
- **PCIe** ( )

:

```
graph LR
    A[USB4 40Gbps    ] --> B{    }

    B -->|  1:    | C[USB 3.2: 40Gbps]

    B -->|  2:   +  | D[DisplayPort: 25Gbps\u003cbr\u003eUSB 3.2: 15Gbps]

    B -->|  3:     | E[PCIe: 32Gbps\u003cbr\u003eDisplayPort: 8Gbps]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#ffe1e1
    style E fill:#ffe1ff
```

[!TIP] , 4K USB , , 40Gbps

#### 2.

USB4 ✅- **USB 3.2**( , Gen 1/Gen 2/Gen ✅2) - **USB 2.0** - ✅**Thunderbolt 3**( ⚠️ ) - **Thunderbolt 4**( , )

:

| **USB4** | | |
|---|---|---|
| USB4 40Gbps | USB4 | 40 Gbps ✅ |
| USB4 40Gbps | USB 3.2 Gen 2 | 10 Gbps ⚠️ |
| USB4 40Gbps | USB 2.0 | 480 Mbps ⚠️ |
| USB 3.2 Gen 2 | USB4 | 10 Gbps ✅ |
| Thunderbolt 3 | USB4 | 40 Gbps ✅ |

**3.**

USB4 : - 40 Gbps (Gen 3x2) - USB PD - DisplayPort Alt Mode( ) - Thunderbolt 3 ( )

[!IMPORTANT] USB4 USB 3.x , "USB4" , " "

---

## 4.5.3 USB4 vs Thunderbolt 3/4

USB4 Thunderbolt, :

| | **USB4** | **Thunderbolt 3** | **Thunderbolt 4** |
|---|---|---|---|
| | 20/40 Gbps | 40 Gbps | 40 Gbps |
| **PCIe** | | (16 Gbps) | (**32 Gbps**) |
| | | (1×4K) | (**2×4K**) |
| **PD** | 7.5W | 15W | 15W |
| | 2m( ) | 2m( ) | 2m( ) |
| | USB-IF | Intel | Intel |
| | USB | ⚡ | ⚡ + 4 |
| | | | |

: - 🎮 ( + ):USB4 - ( ):Thunderbolt 4 - :USB 3.2 Gen 2

---

## 4.5.4 USB4 v2.0 (2022)

USB4 2.0 :

- **80 Gbps**( )
- **120 Gbps**( , 120 Gbps, 40 Gbps)
- :8K

: 2024 ,USB4 2.0 ,

---

# 4.6

≠ :

### 4.6.1

: 10GB 4K ( )

| USB | | | | | 10GB | |
|---|---|---|---|---|---|---|
| **USB 2.0** | 480 Mbps | - | - | 35 MB/s | ~4 50 | ⭐ |
| **USB 3.0 (Gen 1)** | 5 Gbps | 80% | 4 Gbps | 350 MB/s | ~30 | ⭐⭐ |
| **USB 3.1 Gen 2** | 10 Gbps | 97% | 9.7 Gbps | 850 MB/s | ~12 | ⭐⭐ |
| **USB 3.2 Gen 2x2** | 20 Gbps | 97% | 19.4 Gbps | 1.6 GB/s | ~6 | ⭐⭐ |
| **USB4 (40Gbps)** | 40 Gbps | 97% | 38.8 Gbps | 3.2 GB/s | ~3 | ⭐⭐ |
| **Thunderbolt 4** | 40 Gbps | 97% | 38.8 Gbps | 3.5 GB/s | ~3 | ⭐⭐ |

### 4.6.2

: 1000 ( 5GB)

[!NOTE] , , :

| USB | | | |
|---|---|---|---|
| USB 2.0 | 35 MB/s | 15 MB/s | -57% |
| USB 3.0 | 350 MB/s | 120 MB/s | -66% |
| USB 3.1 Gen 2 | 850 MB/s | 250 MB/s | -71% |
| USB4 | 3200 MB/s | 800 MB/s | -75% |

: - ( ): USB - ( ): , - : , ( ZIP)

---

### 4.6.3

**1:** (5000 , 20GB)

| USB | | |
|---|---|---|
| USB 2.0 | 12 | ❌ , |
| USB 3.0 | 1.5 | ✅ |
| USB 3.1 Gen 2 | 40 | ✅ |

**2: 4K ( 50GB )**

| USB | | |
|---|---|---|
| USB 2.0 | 25 | ❌ |
| USB 3.0 | 2.5 | ⚠️ |
| USB 3.1 Gen 2 | 1 | ✅ |
| USB4 | 15 | ✅ |

**3: ( SSD 100GB )**

| USB | 4K | 8K |
|---|---|---|
| USB 2.0 | ❌ | ❌ |
| USB 3.0 | ⚠️ , | ❌ |
| USB 3.1 Gen 2 | ✅ | ⚠️ |
| USB4 / Thunderbolt 4 | ✅ | ✅ |

## 4.7 USB

USB , ?

### 4.7.1 1:

USB-IF , :

| | | |
|---|---|---|
| **SS** | SuperSpeed | USB 3.0 (5 Gbps) |
| **SS 5** | SuperSpeed 5Gbps | USB 3.0 (5 Gbps) |
| **SS 10 SS+** | SuperSpeed 10Gbps | USB 3.1 Gen 2 (10 Gbps) |
| **SS 20** | SuperSpeed 20Gbps | USB 3.2 Gen 2x2 (20 Gbps) |
| **USB 40Gbps USB4 40** | USB4 | USB4 (40 Gbps) |
| ⚡ | Thunderbolt | Thunderbolt 3/4 (40 Gbps) |
| ⚡ **4** | Thunderbolt 4 | Thunderbolt 4 (40 Gbps) |

### 4.7.2 2: ( Type-A )

| | | | |
|---|---|---|---|
| ⚫ | / | USB 2.0 | 480 Mbps |
| 🔵 | | USB 3.0 / 3.1 Gen 1 | 5 Gbps |
| 🔵 | **(Teal)** | USB 3.1 Gen 2 | 10 Gbps |
| 🔴 | | USB 3.2 / | 20 Gbps |
| 🟡 | | | ( ) |

[!WARNING] , ,

---

### 4.7.3 3:

:

**U** :

```
    : SanDisk Extreme PRO USB 3.2
    : USB Type-A
    : USB 3.2 Gen 2 (10 Gbps)  ←
    :    420 MB/s              ←
    :    380 MB/s
```

:

```
    : Samsung T7
    : USB Type-C
    : USB 3.2 Gen 2 (10 Gbps)  ←
    :    1050 MB/s
    :    1000 MB/s
```

[!TIP] 10 Gbps ≈ 1250 MB/s, 1000 MB/s

---

### 4.7.4 4:

**Windows**: - " " → " " - " "

**macOS**: - " " → "USB" - " " ( " 10 Gb/s")

: - **USBTreeView** (Windows): USB - **USB Device Tree Viewer**: USB - **CrystalDiskMark**:

---

## 4.8

USB , ,

### 4.8.1

```
graph TB
    A[USB4   \u003cbr\u003e40Gbps   ] --> B{   }

    B -->|USB4   | C[    \u003cbr\u003e40✅bps   ]

    B -->|USB 3.2 Gen 2   | D[    \u003cbr\u003e10⚠️bps   ]

    B -->|USB 3.0   | E[    \u003cbr\u003e5⚠️bps   ]

    B -->|USB 2.0   | F[    \u003cbr\u003e480❌bps   ]

    style A fill:#e1f5ff
```

```
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#fffacd
    style E fill:#ffe4b5
    style F fill:#ffe1e1
```

### 4.8.2

[!IMPORTANT] : 1. (U ) 2. ( USB ) 3. (USB )

:

| | | | |
|---|---|---|---|
| USB4 SSD (40Gbps) | USB4 | USB4 | 40 Gbps ✅ |
| USB4 SSD (40Gbps) | USB 3.1 Gen 2 | USB 3.1 | 10 Gbps ⚠️ |
| USB 3.1 Gen 2 (10Gbps) | USB4 | USB 2.0 | 480 Mbps ❌ |
| USB 3.0 U (5Gbps) | USB4 | USB4 | 5 Gbps ⚠️ |

---

### 4.8.3 Type-C

Type-C , :

```
graph LR
    A[Type-C   \u003cbr\u003e    ] --> B[  USB 2.0\u003cbr\u003e480Mbps]
    A --> C[USB 3.0\u003cbr\u003e5Gbps]
    A --> D[USB 3.1 Gen 2\u003cbr\u003e10Gbps]
    A --> E[USB 3.2 Gen 2x2\u003cbr\u003e20Gbps]
    A --> F[USB4\u003cbr\u003e40Gbps]
    A --> G[Thunderbolt 4\u003cbr\u003e40Gbps]

    style A fill:#fff4e1
    style B fill:#ffe1e1
    style C fill:#fffacd
    style D fill:#e1ffe1
    style E fill:#e1f5ff
    style F fill:#e1f5ff
    style G fill:#ffe1ff
```

[!CAUTION] **Type-C =** Type-C USB 2.0, 480Mbps, USB 3.0 Type-A !

---

## 4.9

, USB

### 4.9.1 U

| | | | |
|---|---|---|---|
| | USB 2.0 / 3.0 | ¥20-50 | DT |
| | USB 3.1 Gen 1 (5Gbps) | ¥50-150 | CZ880 DT100 G3 |
| / | USB 3.1 Gen 2 (10Gbps) | ¥150-400 | BAR Plus |
| | USB 3.2 Gen 2 | ¥400+ | Extreme PRO |

: - ✅ , ✅ - (✅128⚠️B) - , - " " ,

---

## 4.9.2 / SSD

| | | | (1TB) |
|---|---|---|---|
| | USB 3.0 (5Gbps) | HDD | ¥300-500 |
| / | USB 3.1 Gen 2 (10Gbps) | SATA SSD | ¥500-800 |
| **4K** | USB 3.2 Gen 2 (10Gbps) | NVMe SSD | ¥800-1500 |
| **8K** / | USB4 / Thunderbolt 3/4 | NVMe SSD | ¥1500+ |

: - **HDD** : , ( 150 MB/s), - **SATA SSD**: 500 MB/s, - **NVMe SSD**: 1000-3500 MB/s,

[!TIP] USB 3.0 , USB4 ,

## 4.9.3 USB

| | | | |
|---|---|---|---|
| | USB 2.0 | ¥10-30 | |
| | USB 3.0 | ¥30-60 | |
| | USB 3.1/3.2 | ¥60-150 | SS 10/20 |
| **100W** | USB-C 5A E-Marker | ¥50-150 | E-Marker |
| / | Thunderbolt 4 | ¥200-500 | ⚡ , 40Gbps |

: 1. : - 1 : - 1-2 : ( ) - 3 : , ( )

1. :
2. ✅ USB-IF : usb.org
3. ✅ Thunderbolt ⚡
4. ⚠️
5. :
6. ( )
7. USB 2.0 USB 3.x

# 4.10 FAQ

## 4.10.1 Q1: USB 3.0 U ?

:

1. **USB 2.0**
2. ✅ : USB 3.0
3. **USB 2.0**
4. ✅ : USB 3.0
5. **U**
6. U USB 3.0, 50-100 MB/s
7. ✅ : U
8. 
9. ,
10. ✅ :
11. 
12. Windows USB 3.0
13. ✅ :

---

## 4.10.2 Q2: USB 3.2 Gen 2x2 Type-C ?

: , **Type-C**

: - USB 3.2 Gen 2x2 (2 TX/RX ) - Type-A **1** TX/RX, - Type-C (24 ) 2

: - Type-A **USB 3.2 Gen 2**(10 Gbps, ) - 20 Gbps Type-C

---

## 4.10.3 Q3: USB4 Thunderbolt 4 ? USB4 ?

:

| | **USB4** | **Thunderbolt 4** |
|---|---|---|
| | 20 Gbps( 40 Gbps) | 40 Gbps |
| **PCIe** | | (32 Gbps) |
| | | (2×4K 1×8K) |
| | | (6 ) |
| | | |

: - ✅ **USB4** **Thunderbolt 4** : , Thunderbo✅ ( PCIe ) - **Thunderbolt 4** **USB4** : , USB4 Thunder✅lt - **USB4** : Thunderbolt 3

---

## 4.10.4 Q4: USB ?

**Windows**: 1. " " → " " → " " 2. " " 3. : - "USB 2.0 " = USB 2.0 - "USB 3.0 " = USB 3.0+ - "USB4 " = USB4

**macOS**: 1. → → " " → " " 2. "USB" "Thunderbolt" 3. (" 10 Gb/s" )

: - 🔵 : USB⚡.0+ - :Thunderbolt -**SS** :

---

## 4.10.5 Q5: Type-C , ?

:

1. (Charge-Only Cable)
2. (VBUS/GND),
3. ✅
4. ❌
5. :¥10-20
6. **USB 2.0**
7. D+/D-
8. ✅ +
9. ⚠️ 480 Mbps
10. :¥20-40
11. **USB 3.x**
12. 
13. ✅ +
14. :5-40 Gbps
15. :¥50-200+

: - (SS 5A 10Gbps ) - , - , " "

---

## 4.10.6 Q6: USB 3.0 USB 2.0, ?

: " ":

**1:USB 3.0 → USB 2.0** - **USB 2.0**(480 Mbps) - ⚠️

**2:USB 2.0 → USB 3.0** - **USB 2.0**(480 Mbps) - ✅ ,

**3:USB 3.0 + USB 2.0 → USB 3.0** - **USB 2.0**(480 Mbps) - ⚠️

[!IMPORTANT] " " " "

---

## 4.10.7 Q7: USB 3.2 USB4 ?

:

**USB 3.2 Gen 2 (10Gbps)** :✅ ( 3✅0%) - U✅ 3.1/✅2 - ( ) -

**USB4 (40Gbps)** :✅ ✅ - USB4 Thund✅olt 3/4 - ✅ (4K/8✅ ) - (eGPU) -

: - 💰 **USB 3.1 Gen 2 (10Gbps)** **SSD** , ,

---

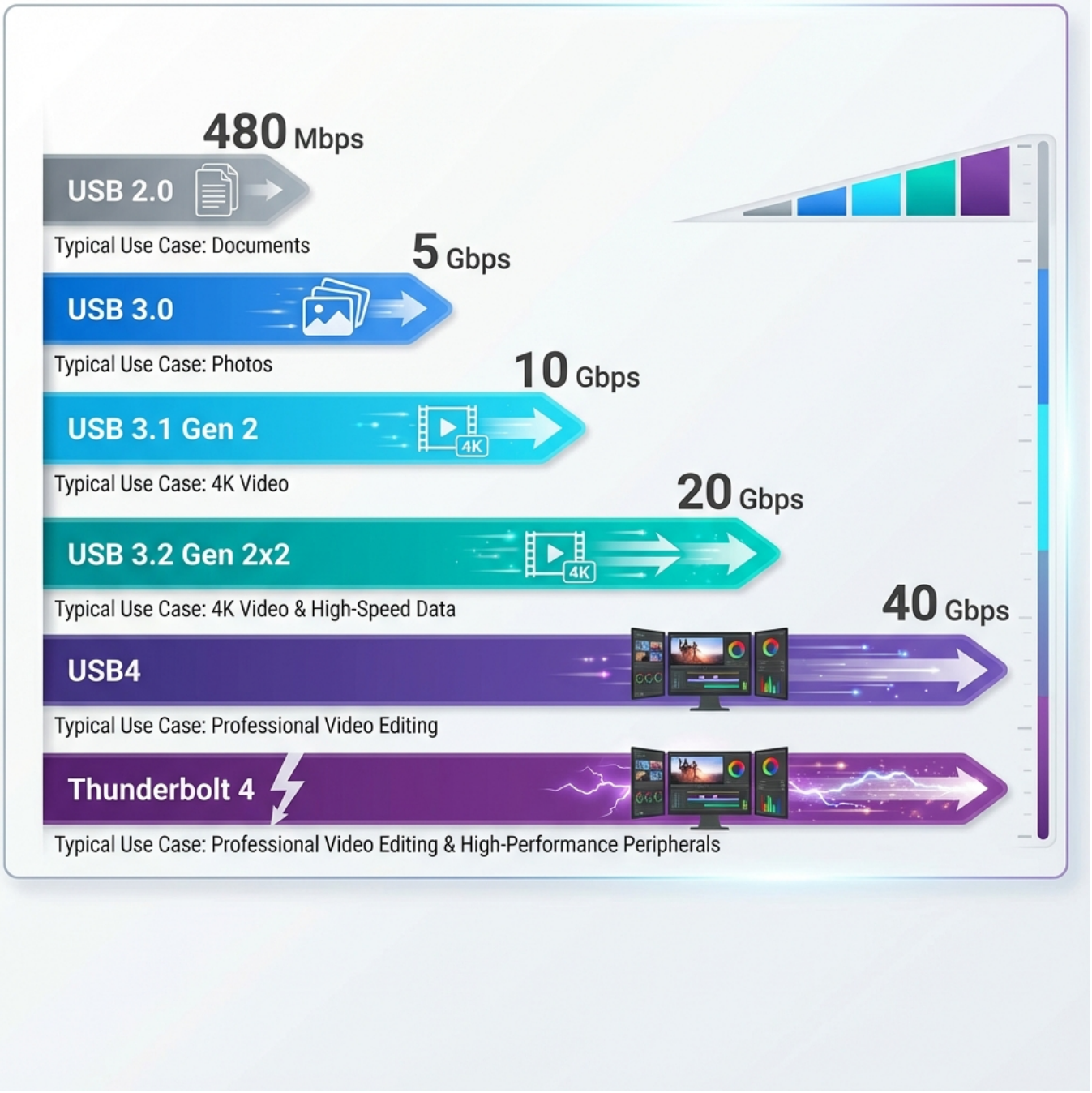
# 4.11

## 4.11.1

| | | | | |
|---|---|---|---|---|
| | | **10GB** | | |
| USB 2.0 | 480 Mbps | ~5 | | ⭐⭐ |
| USB 3.0 (Gen 1) | 5 Gbps | ~30 | | ⭐⭐⭐⭐ |
| USB 3.1 Gen 2 | 10 Gbps | ~12 | | ⭐⭐⭐⭐⭐ |
| USB 3.2 Gen 2x2 | 20 Gbps | ~6 | 4K | ⭐⭐⭐⭐ |
| USB4 | 40 Gbps | ~3 | | ⭐⭐⭐⭐⭐ |
| Thunderbolt 4 | 40 Gbps | ~3 | + | ⭐⭐⭐⭐⭐ |

# 4.12

- :USB-IF
- :USB-IF
- :CrystalDiskMark ATTO Disk Benchmark
- :
- 2 :USB -
- 4 :Thunderbolt -



# 5. 4 Thunderbolt ( ) (Thunderbolt Technology)

Thunderbolt **Intel** **Apple** , " " " PCIe DisplayPort ,

## 5.1 Thunderbolt?

Thunderbolt , :

- :USB , eGPU
- : (HDMI DP DVI)
- : USB 3.0, 4K/8K
- :
- :

**Thunderbolt** :

- ⚡ : 40 Gbps(Thunderbolt 3/4) 120 Gbps(Thunderbolt 5)
- 🎮 : PCIe eGPU,
- 🖥️ : 2-4 4K
- 🔌 : + + + ,
- 🔗 : 6 ,

[!IMPORTANT] Thunderbolt , MacBook Pro Windows

## 5.2 Thunderbolt

```
timeline
    title Thunderbolt
    2011 : Thunderbolt 1    : 10 Gbps    : Mini DisplayPort   \u003cbr\u003eApple MacBook Pro
    2013 : Thunderbolt 2 : 20 Gbps :       \u003cbr\u003e   4K
    2015 : Thunderbolt 3    : 40 Gbps :      \u003cbr\u003e   USB Type-C
    2016 : MacBook Pro      :   Thunderbolt 3    :   "    "
    2020 : Thunderbolt 4    : 40 Gbps(    ) :         \u003cbr\u003e   PCIe 32Gbps
    2020 : Intel      : Thunderbolt 3     USB4 :
    2023 : Thunderbolt 5    : 80/120 Gbps :       \u003cbr\u003e     8K
```

## 5.3 Thunderbolt

### 5.3.1 :

Thunderbolt **Protocol Tunneling( )** , :

```
graph TB
    A[Thunderbolt    ] --> B[40 Gbps    ]

    B --> C[PCIe   \u003cbr\u003e   32 Gbps]
    B --> D[DisplayPort   \u003cbr\u003e   17.28 Gbps]
    B --> E[USB   \u003cbr\u003e   10 Gbps]
    B --> F[    \u003cbr\u003e   100W]

    C --> G[     eGPU\u003cbr\u003eNVMe SSD\u003cbr\u003e      ]
    D --> H[4K/5K/8K    \u003cbr\u003e      ]
    E --> I[USB   \u003cbr\u003eU        ]
    F --> J[     \u003cbr\u003e    ]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#ffe1e1
    style D fill:#e1ffe1
```

```
    style E fill:#ffe1ff
    style F fill:#ffffe1
```

:

Thunderbolt :

| | **PCIe** | **DisplayPort** | **USB** | |
|---|---|---|---|---|
| | 32 Gbps | 0 | 8 Gbps | NVMe SSD |
| **4K +** | 16 Gbps | 12 Gbps | 8 Gbps | |
| **4K** | 8 Gbps | 25 Gbps | 5 Gbps | |
| **eGPU +** | 28 Gbps | 8 Gbps | 2 Gbps | / |

[!NOTE] Thunderbolt USB USB4 , Thunderbolt

## 5.4 Thunderbolt

### 5.4.1

| | **Thunderbolt 1** | **Thunderbolt 2** | **Thunderbolt 3** | **Thunderbolt 4** | **Thunderbolt 5** |
|---|---|---|---|---|---|
| | 2011 | 2013 | 2015 | 2020 | 2023 |
| | 10 Gbps | 20 Gbps | 40 Gbps | 40 Gbps | **120 Gbps** |
| | Mini DP | Mini DP | **Type-C** | Type-C | Type-C |
| **PCIe** | 10 Gbps | 20 Gbps | 16-32 Gbps | **32 Gbps** | 64 Gbps |
| **DisplayPort** | 1.1a | 1.2 | 1.2/1.4 | 1.4 | 2.1 |
| | 1×2K | 1×4K | 2×4K 1×5K | **2×4K** | 3×4K 2×8K |
| **USB** | ❌ | ❌ | ✅ USB 3.1 | ✅ USB4 | ✅ USB4 v2 |
| | N/A | N/A | 100W | 100W | 140W(EPR) |
| | 6 | 6 | 6 | 6 | 6 |
| | 3m( ) | 3m( ) | 0.8m( 40G) \u003cbr\u003e2m( ) | 0.8m( ) \u003cbr\u003e2m( ) | 1m( 80G) \u003cbr\u003e3m( ) |
| **DMA** | ❌ | ❌ | | (VT-d) | |
| | Mac | Mac/PC | | | |

### 5.4.2 Thunderbolt 1 & 2:

**Thunderbolt 1 (2011)**

- : Mini DisplayPort
- : 10 Gbps( , 10 Gbps)
- : Apple MacBook Pro(2011 )
- : Intel Light Peak ( )

: - ❌ , Apple ❌ PC - ❌ ( $50+) -

**Thunderbolt 2 (2013)**

- : 20 Gbps( 10 Gbps )
- : 4K@60Hz
- :

: - ✅ , ✅K - PC (Dell HP )

: - ❌ Mini DP❌ , - ,

---

## 5.4.3 Thunderbolt 3:

2015 Thunderbolt 3 , " " " "

1. **USB Type-C** 🔌

✅ : - ✅ ,✅USB-C ⚠️ , - Type-C - :" Type-C" USB 3.x Thunderbolt

2. **40 Gbps** ⚡

- 40 Gbps
- **PCIe 3.0 x4**(32 Gbps)
- (eGPU)

3. **USB 3.1** 🔗

- USB 3.1 Gen 2(10 Gbps)
- USB-C
- Thunderbolt 3 USB

4. 🖥️

- **2 4K@60Hz 1 5K@60Hz**
- DisplayPort 1.2 HBR2(17.28 Gbps)

5. 🔋

- USB PD, **100W**(20V 5A)
- Thunderbolt

| | |
|---|---|
| | |
| | 40 Gbps( ) |
| | USB Type-C |
| **PCIe** | Gen 3.0 x4( 32 Gbps) |
| **DisplayPort** | 1.2 HBR2 / 1.4 HBR3 |
| **USB** | USB 3.1 Gen 2(10 Gbps) |
| | USB PD 3.0( 100W) |
| | 6 |
| | :0.5m(40Gbps)\u003cbr\u003e :1-2m(40Gbps) |

#### Thunderbolt 3

**Intel** :

**Alpine Ridge( )**: - PCIe : 16 Gbps - 4K : - :

**Titan Ridge( )**: - PCIe : **32 Gbps** - 4K : - DisplayPort 1.4: - :

[!WARNING] Thunderbolt 3 "Thunderbolt 3", 16 Gbps PCIe, 32 Gbps Thunderbolt 4

---

## 5.4.4 Thunderbolt 4:

Thunderbolt 4 ( 40 Gbps), ,

**1. PCIe 32 Gbps 💪**

- Thunderbolt 3 16 Gbps
- Thunderbolt 4 32 Gbps
- eGPU SSD

**2. 4K** 🖥️🖥️

- Thunderbolt 3
- Thunderbolt 4 2×4K@60Hz 1×8K@60Hz

**3. (Hub)** 🔌

- Thunderbolt 3 ( )
- Thunderbolt 4 (1 3)

```
graph LR
    A[   \u003cbr\u003eThunderbolt 4] -->|    | B[     ]

    B --> C[   TB4   1\u003cbr\u003e   SSD]
    B --> D[   TB4   2\u003cbr\u003e4K    ]
    B --> E[   TB4   3\u003cbr\u003e    ]
    B --> F[USB-A  ×3]
    B --> G[    ]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#e1ffe1
    style E fill:#e1ffe1
```

**4. DMA** 🔒

- **Intel VT-d DMA** : Thunderbolt DMA
- Thunderbolt 3 ,Thunderbolt 4

**5. USB4** 🔗

- USB4
- USB4 TB4
- TB4 USB4 ( )

**6.** 📏

- : **0.8m**, 40 Gbps
- : **2m**, 40 Gbps
- TB4 USB4 TB3 USB 3.2 USB 2.0
- TB4 100W USB PD

#### Thunderbolt 4 vs Thunderbolt 3

| | **Thunderbolt 3** | **Thunderbolt 4** |
|---|---|---|
| | 40 Gbps | 40 Gbps( ) |
| **PCIe** | 16 Gbps( )\u003cbr\u003e32 Gbps( ) | **32 Gbps** |
| | 1-2 4K( ) | **2 4K** |
| | | |
| **DMA** | | **VT-d** |
| **USB4** | | |
| | 0.5-2m | **0.8m( )** |
| | | |

[!IMPORTANT] :Thunderbolt 4 , ,Thunderbolt 4

---

## 5.4.5 Thunderbolt 5:

2023 9 ,Intel **Thunderbolt 5**,

- **( )**: 80 Gbps( 80 Gbps)
- **( Bandwidth Boost)**: 120 Gbps( )+ 40 Gbps( )
- **PCIe**: Gen 4.0 x4(64 Gbps)
- **DisplayPort**: 2.1(80 Gbps)
- **USB**: USB4 v2(80 Gbps)
- : USB PD 3.1 EPR( 140W,28V 5A)

#### Bandwidth Boost

Thunderbolt 5 :

( ): - : 80 Gbps - : 80 Gbps - : 160 Gbps

(Boost): - ( ): **120 Gbps** - ( ): 40 Gbps - : ( 8K )

```
graph LR
    A[Thunderbolt 5\u003cbr\u003e    160 Gbps] --> B{    }

    B -->|    | C[   80 Gbps\u003cbr\u003e   80 Gbps]
    B -->|Boost   | D[   120 Gbps\u003cbr\u003e   40 Gbps]

    C --> E[      \u003cbr\u003e :       ]
    D --> F[     \u003cbr\u003e :3×8K    ]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#ffe1e1
```

1. - 3× 4K@144Hz - 2× 8K@60Hz - 1× 16K ( )
2. **eGPU** - PCIe 4.0 x4(64 Gbps) - ( 10%,Thunderbolt 3/4 15-20%)
3. - PCIe 4.0 NVMe SSD - **8000+ MB/s**

- : 2023 9
- : 2024
- : 2025-2026
- : 2024

[!NOTE] Thunderbolt 5 (2024 ) , , ,Thunderbolt 4

---

## 5.5 Thunderbolt vs USB4

Thunderbolt USB4,

### 5.5.1

```
graph TB
    A[2015\u003cbr\u003eThunderbolt 3   \u003cbr\u003e40 Gbps] --> B[2019\u003cbr\u003eIntel    TB3   \u003cbr\u003e    USB-IF]

    B --> C[2019\u003cbr\u003eUSB4     \u003cbr\u003e   TB3]

    C --> D[2020\u003cbr\u003eThunderbolt 4\u003cbr\u003e      ]

    D --> E{    }

    E --> F[USB4\u003cbr\u003e    \u003cbr\u003e     ]
    E --> G[Thunderbolt 4\u003cbr\u003eIntel   \u003cbr\u003e    ]

    style A fill:#ffe1e1
    style B fill:#fff4e1
    style C fill:#e1f5ff
    style D fill:#ffe1ff
    style E fill:#fffacd
    style F fill:#e1ffe1
    style G fill:#e1ffe1
```

## 5.5.2

| | USB4 | Thunderbolt 4 |
|---|---|---|
| | (USB-IF) | Intel |
| | 20 Gbps | **40 Gbps** |
| | 40 Gbps | 40 Gbps |
| **PCIe** | (0-32 Gbps) | **32 Gbps** |
| **DisplayPort** | | (2×4K) |
| **USB 3.2** | | |
| | | |
| | | |
| **DMA** | | **VT-d** |
| | | |
| | | Intel |
| | | |
| | | / |

## 5.5.3

| | | | |
|---|---|---|---|
| **Thunderbolt 4** | Thunderbolt 4 | ✅ | (40G + PCIe 32G) |
| Thunderbolt 4 | USB4 | ✅ | USB4 \u003cbr\u003e PCIe |
| Thunderbolt 4 | USB 3.2 | ✅ | 10-20 Gbps |
| Thunderbolt 4 | Thunderbolt 3 | ✅ | |
| **USB4** | Thunderbolt 4 | ✅ | USB4 |
| USB4 | USB4 | ✅ | |
| **Thunderbolt 3** | Thunderbolt 4 | ✅ | |
| Thunderbolt 3 | USB4 | ⚠️ | USB4 TB3 |

[!IMPORTANT] : - → **Thunderbolt 4** - , PCIe(eGPU) → **USB4** - **USB** → **USB 3.2**

### 5.5.4 Thunderbolt 4 ?

| | USB4 | Thunderbolt 4 |
|---|---|---|
| | , $5-30 | Intel ,$30-50 |
| | | Intel |
| | | |
| | | ( ) |
| **PCB** | | ( ) |

: - USB4 : ¥300-800 - Thunderbolt 4 : ¥1000-3000 - : **2-4**

## 5.6 Thunderbolt

### 5.6.1 1. (Daisy Chain)

**6** ,

```
graph LR
    A[   \u003cbr\u003eThunderbolt   ] -->|TB   | B[   1\u003cbr\u003e   ]
    B -->|TB   | C[   2\u003cbr\u003e   SSD]
    C -->|TB   | D[   3\u003cbr\u003e    ]
    D -->|TB   | E[   4\u003cbr\u003eUSB Hub]
    E -->|TB   | F[   5\u003cbr\u003e      ]
    F -->|TB   | G[   6\u003cbr\u003e    ]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#fffacd
    style D fill:#e1ffe1
    style E fill:#ffe1e1
    style F fill:#ffe1ff
    style G fill:#ffffe1
```

: - **Thunderbolt** : 6 - **DisplayPort** : ( ) - **USB** ( TB Hub):

:

**40 Gbps** :

| | | |
|---|---|---|
| 1 | 4K | 32 Gbps |
| 2 | 4K | 12 Gbps |
| 1 | eGPU + | eGPU: 28G, : 8G, : 4G |

[!WARNING] : - , - , - , - Thunderbolt ( )

### 5.6.2 2. PCIe :eGPU

Thunderbolt **PCIe**

**eGPU**

```
graph TB
    A[    CPU/  ] -->|Thunderbolt 4\u003cbr\u003ePCIe 3.0 x4| B[eGPU    ]

    B --> C[GPU\u003cbr\u003e  RTX 4070]
    B --> D[    \u003cbr\u003e400-750W]

    C --> E[    ]
    E --> F[     \u003cbr\u003e4K@144Hz]

    C -.      .-> G[       ]

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#ffe1e1
    style D fill:#ffffe1
    style E fill:#e1ffe1
    style F fill:#ffe1ff
    style G fill:#fffacd
```

**eGPU**

Thunderbolt ,eGPU :

| **GPU** | | **eGPU(TB3/4)** | |
|---|---|---|---|
| RTX 4060 | 100% | 85-90% | 10-15% |
| RTX 4070 | 100% | 80-85% | 15-20% |
| RTX 4090 | 100% | 70-75% | 25-30% |

: - PCIe 3.0 x4(32 Gbps) vs PCIe 4.0 x16(256 Gbps) - -

[!TIP] **eGPU** : - ( GPU, ) - **GPU**(RTX 4060-4070 Ti), - Thunderbolt **32 Gbps PCIe**(TB4 TB3) -

---

### 5.6.3 3.

Thunderbolt USB PD,

| **Thunderbolt** | |
|---|---|
| Thunderbolt 3 | 100W(20V 5A) |
| Thunderbolt 4 | 100W(20V 5A) |
| Thunderbolt 5 | **140W**(28V 5A, EPR) |

:

⚡ : - 🖥️(65-100W)💾 (2 🌐4K ) - 🎧 ( SSD🖱️U ) - ( /2.5G ) - (DAC ) - USB ( )

, ,

---

## 5.7 Thunderbolt

### 5.7.1 Thunderbolt ?

**1.**

**Thunderbolt 3/4/5**: - ⚡ (Thunderbolt Logo) - :"3" "4" "5" - "40" "USB4"

: - ⚡ = Thunderbolt 3 - ⚡ 4 = Thunderbolt 4 - ⚡ 5 = Thunderbolt 5

[!WARNING] Thunderbolt!

**2.**

**macOS**: 1. Apple →" "→" " 2. "Thunderbolt" "USB" 3.

**Windows**: 1. " "→" "→" " 2. " " 3. "Thunderbolt(TM) Controller"

**Linux**:

```
lspci | grep Thunderbolt
sudo dmesg | grep thunderbolt
```

**3. (Type-C )**

Thunderbolt 3/4/5 Type-C, ⚡ : - - ( + + ) - MacBook Pro Thunderbolt

---

## 5.7.2 Thunderbolt

| | | | | |
|---|---|---|---|---|
| **TB3** | 40 Gbps | ≤0.5m | ¥80-200 | , |
| **TB3** | 40 Gbps | 1-2m | ¥200-500 | , |
| **TB4** | 40 Gbps | ≤0.8m | ¥150-300 | , |
| **TB4** | 40 Gbps | 2m | ¥300-800 | |

: - ✅ Intel Thunderbolt Certified - ✅ 50 ( USB PD 5A✅ ) - SS 40( 40 Gbps)

---

**(¥800-1500)**: - 1 TB4 - 2-3 USB-A - 1 HDMI 2.0(4K@60Hz) - - 65W - : CalDigit Belkin Anker

**(¥1500-2500)**: - 1 TB4 - 2-3 TB4 - USB-A/C - HDMI DP( 4K) - 2.5G - 85-96W - SD - : OWC CalDigit TS4

**(¥2500-4000+)**: - 3 TB4 - DisplayPort 1.4 - 10G - 96-100W - DAC - : OWC Thunderbolt Dock CalDigit TS4

[!TIP] : 1. : ( ) 2. **TB** : TB ( SSD) 3. : 4. : 2.5G 10G 5. : Intel ,

---

| | (1TB) | | |
|---|---|---|---|
| **TB3 HDD** | 200 MB/s | ¥600-1000 | LaCie G-Tech |
| **TB3 SATA SSD** | 500 MB/s | ¥800-1500 | Samsung X5 |
| **TB3 NVMe SSD** | 1500-2800 MB/s | ¥1500-3000 | Samsung X5 OWC Envoy Pro |
| **TB4 NVMe SSD** | 2000-3000 MB/s | ¥2000-4000 | OWC Envoy Pro Acasis |

**eGPU**

| / | | PCIe | | |
|---|---|---|---|---|
| **Razer Core X** | 650W | x16(TB@x4) | 4×USB, | ¥2000-2800 |
| **Sonnet eGFX Breakaway Box** | 550W | x16 | | ¥1500-2200 |
| **AORUS Gaming Box** | 450W | x16 | 3×USB | ¥2500-3500( GPU) |

: - ≥ GPU TDP + 100W - GPU - macOS GPU (AMD )

## 5.8 Thunderbolt

### 5.8.1 1

: - MacBook Pro 16"(M3 Max,Thunderbolt 4) - OWC Thunderbolt Dock(3×TB4 ) - 2× 4K ( ) - 4TB NVMe SSD(TB4, ) - 8TB HDD( ,USB)

: - : , - : , - 4K :2500 MB/s,100GB 40

### 5.8.2 2: + eGPU

: - (Thunderbolt 4) - Razer Core X eGPU Box - RTX 4070 - 2K@165Hz

: - : (1.3kg) - : eGPU, 5-8 - : +

: - 2077 :2K 80-100 FPS - :2K 120 FPS - : 15%( )

### 5.8.3 3

: - MacBook Pro 14" - Universal Audio Apollo Twin( ) - MIDI (USB) -

: - : <2ms(USB 5-10ms) - **DSP** :Apollo DSP, CPU - : 10+

### 5.8.4 4

: - MacBook Pro 16" - OWC Envoy Pro(2TB NVMe SSD, ) - SD (USB-C) - CalDigit TS4 ( )

: 1. (SD ) 2. SSD( 500+ MB/s) 3. SSD (Lightroom Photoshop) 4. : , NAS

: - 64GB RAW : 2 (USB 3.0 10+ ) - PSD : 2500 MB/s,

# 5.9 FAQ

## 5.9.1 Q1: Thunderbolt USB-C ?

:

- **USB-C**: ( ),Type-C :
- USB 2.0(480 Mbps)
- USB 3.2(10-20 Gbps)
- USB4(20-40 Gbps)
- Thunderbolt 3/4/5(40-120 Gbps)
- **Thunderbolt**: ,Thunderbolt 3/4/5 Type-C , Type-C ≠ Thunderbolt

: ⚡

---

## 5.9.2 Q2: Type-C , Thunderbolt ?

: , Type-C

:

| | Thunderbolt | | |
|---|---|---|---|
| **Thunderbolt 4** | TB4/TB3 | ✅ | |
| **Thunderbolt 3** | TB4/TB3 | ✅ | (TB3 ) |
| **USB4** | TB4/TB3 | ⚠️ | PCIe |
| **USB 3.2** | TB | ⚠️ | USB , TB |
| **USB 2.0 Type-C** | TB | ⚠️ | 480 Mbps, |

[!IMPORTANT] eGPU Thunderbolt USB-C

---

## 5.9.3 Q3: Thunderbolt , ?

:

: - ✅ ✅ - U✅B (U ) - (<0.5m)

: - ❌ 40 Gbps ❌ - eGPU❌ ❌ - 100W ( ❌A E-Marker ) - (>1m)

: - - -

[!WARNING] Thunderbolt , ¥20 ¥20000 !

---

### 5.9.4 Q4: Mac Windows PC Thunderbolt ?

: ,

| | Mac | Windows PC |
|---|---|---|
| **Thunderbolt** | MacBook Pro/Air | / |
| | Apple | |
| | , | |
| **eGPU** | macOS ( AMD ) | Windows (NVIDIA/AMD) |
| | | BIOS |
| | | |

: - **Mac** : eGPU AMD (RX 6000/7000 ) - **Windows** : eGPU NVIDIA(RTX , )

---

### 5.9.5 Q5: Thunderbolt , ?

:

**1.** - Thunderbolt( ) - Thunderbolt

**2.** - Thunderbolt -

**3.** - **Windows**: Intel Thunderbolt - **Mac**: macOS - ( eGPU)

**4. BIOS/** - **Windows PC**: BIOS, Thunderbolt - "Thunderbolt Boot Support" - **Mac**: → → Thunderbolt

**5.** - (Thunderbolt ) - eGPU

**6. SMC/NVRAM(Mac)**

```
SMC:    →   Shift+Control+Option+    10
NVRAM:      Command+Option+P+R,
```

---

### 5.9.6 Q6: Thunderbolt ? ?

:

**1. DMA (Direct Memory Access)**

- Thunderbolt
-
- :
- Thunderbolt 4( VT-d DMA )
- Windows: "Kernel DMA Protection"
- Mac: → → Thunderbolt

**2. Thunderspy**

• 2020
• Thunderbolt 1/2/3(2019 )
• :
• Thunderbolt 4( )
•
• Secure Boot

:

• ✅ Thunderbolt
• ✅ Thunderbolt
• ✅
• ✅ (FileVault BitLocker)
• ✅ Thunderbolt 4

---

### 5.9.7 Q7: Thunderbolt 5 ? ?

**Thunderbolt 5 (2024 ):**

• : 2023 9
• : 2024
• : 2024 -2025
• : 2025-2026

: - ( 50-100%) - 2026

:

**Thunderbolt 4** :✅ ✅ 1-2 ) - Thunderbolt 4✅ 40 Gbps - (TB5 )

**Thunderbolt 5** :✅ 3 4K ✅ 2 8K - ✅ ✅ NVMe SSD - , - 1-2

[!TIP] ,**Thunderbolt 4** **2024-2025** TB5 120 Gbps " "

---

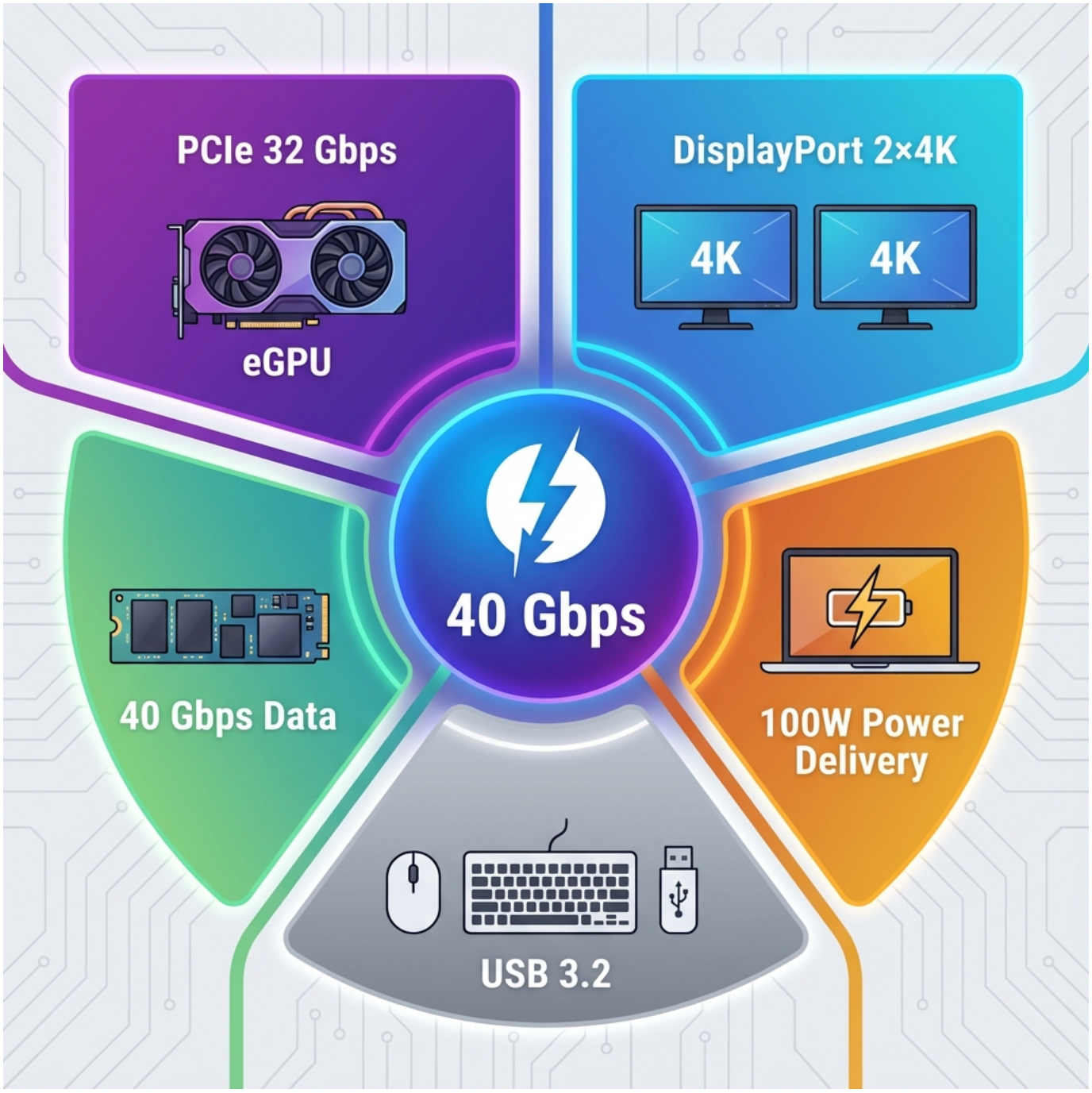
## 5.10

### 5.10.1 Thunderbolt

| | TB1 | TB2 | TB3 | TB4 | TB5 |
|---|---|---|---|---|---|
| | 10 Gbps | 20 Gbps | 40 Gbps | 40 Gbps | 120 Gbps |
| | Mini DP | Mini DP | Type-C | Type-C | Type-C |
| **PCIe** | 10G | 20G | 16-32G | **32G** | 64G |
| | 1×2K | 1×4K | 2×4K | **2×4K** | 3×4K/2×8K |
| **USB** | ❌ | ❌ | USB 3.1 | USB4 | USB4 v2 |
| | - | - | 100W | 100W | 140W |
| | | | | | |

## 5.11

- : Thunderbolt Technology
- : Thunderbolt Certified Products
- : Intel Thunderbolt Specifications
- :
- 2 :USB - Type-C
- 3 :USB - USB4 vs Thunderbolt
- 5 : - USB PD Thunderbolt



# 6. 5 (Charging & Power Delivery)

USB 2.5W (5V 0.5A) 240W

## 6.1

### 6.1.1 USB BC 1.2 (Battery Charging)

USB BC 1.2 USB-IF 2010

- 7.5W (5V 1.5A)
- D+/D-
-
- **SDP (Standard Downstream Port)** USB 500mA
- **CDP (Charging Downstream Port)** + 1.5A
- **DCP (Dedicated Charging Port)** 1.5A
-

## 6.2

### 6.2.1

2010

- **USB 2.0** USB **2.5W** (5V 0.5A) 4-6
- **USB BC 1.2** 7.5W (5V 1.5A)
- USB PD 1.0 2012 2016 PD 3.0
-
- " 5 2 "
-
- 2013-2016 USB PD

OPPO " "

[!IMPORTANT]

### 6.2.2

```
timeline
    title
    2010 : USB BC 1.2 (7.5W) :
    2012 : USB PD 1.0 :    PD   <br>
    2013 :    QC 1.0 (10W) :
    2014 :    QC 2.0 (18W) :
         : OPPO VOOC (20W) :
    2015 :    FCP (18W) :
         :     PE+ : MTK
    2016 :    QC 3.0 : 200mV
         :    SCP (22.5W) :      <br>
         : USB PD 3.0 :
         : vivo     (22.5W)
    2017 :     PE 3.0 (30W)
         :    QC 4 :      USB PD
    2018 : OPPO SuperVOOC (50W) :
         :    (27W)
         :    QC 4+
```

```
    2019 : OPPO SuperVOOC 2.0 (65W)
         :    SCP 2.0 (40W)
    2020 :    QC 5 (100W+) :      PD
         :    (120W)
    2021 : OPPO 125W/240W :
         :    (210W)
         : vivo (200W)
    2023 :      Type-C :
```

## 6.2.3

Handshake Protocol

```
graph LR
    A[    <br/>5V   ] --> B[    <br/>D+/D-   ]
    B --> C[    <br/>    ]
    C --> D[    <br/>  /   ]
    D --> E[    <br/>    ]
    E -->|  /    | F[     ]
    E -->|  | D

    style A fill:#e1f5ff
    style B fill:#fff4e1
    style C fill:#ffe1f5
    style D fill:#e1ffe1
    style E fill:#ffe1e1
    style F fill:#ff9999
```

1. 5V
2. D+/D-
3.
4. /
5.

[!NOTE] D+/D- USB " "

```
graph TB
    A[      ] --> B[      ]
    A --> C[      ]
    A --> D[  /    ]

    B --> B1[   QC 2.0/3.0<br/>9V-20V]
    B --> B2[   FCP<br/>9V/12V]
    B --> B3[   AFC<br/>9V]
    B --> B4[   mCharge<br/>    ]
    B --> B5[    PE<br/>5V-12V]

    C --> C1[OPPO VOOC<br/>5V 4A-5A]
    C --> C2[OPPO SuperVOOC<br/>10V 5A-12.5A<br/> /   ]
    C --> C3[   SCP<br/>4.5V-11V<br/>    ]
    C --> C4[vivo FlashCharge<br/>  +   ]

    D --> D1[   QC 4+<br/>   USB PD]
    D --> D2[  <br/>QC + PD   ]
    D --> D3[    <br/>PD + PPS]

    style B fill:#ffe1e1
    style C fill:#e1ffe1
    style D fill:#e1f5ff
```

## 6.2.4 Quick Charge (QC)

Quick Charge Android

**QC 1.0 (2013)**

- 10W (5V 2A)

- 
- 

#### QC 2.0 (2014)

QC 2.0

- 18W
- 
- Class A: 5V 9V 12V
- Class B: 5V 9V 12V 20V
- 3A
- D+/D-
- 5V D+ = D- = 0.6V
- 9V D+ = 3.3V, D- = 0.6V
- 12V D+ = 0.6V, D- = 0.6V
- 20V D+ = 3.3V, D- = 3.3V Class B

#### QC 3.0 (2016)

QC 3.0

- 18W 22W
- 3.6V - 20V
- **200mV** QC 2.0
- 
- 
- **38%** QC 2.0
- 
- QC 2.0

#### QC 4 / QC 4+ (2017-2018)

QC 4/4+ USB PD

- 28W (QC 4) 100W (QC 4+)
- 
- **USB PD 3.0** PD
- **PPS (Programmable Power Supply)**
- **INOV (Intelligent Negotiation for Optimum Voltage)**
- QC USB PD
- 

#### QC 5 (2020)

- **100W+**
- 98%

- USB PD QC

[!IMPORTANT] QC 4 USB PD QC 4+ PD iPhone MacBook

## 6.2.5 OPPO VOOC

OPPO VOOC

**VOOC (2014)**

- 20W
- / **5V 4A**
-
- QC 5V 4A-5A
- **7 Micro-USB** 5 2
-
- **MCU ( )**
-
-
-

**SuperVOOC (2018)**

SuperVOOC

- 50W
- / **10V 5A**
-
- 2000mAh
- 10V 5V
- 5V 10V 5A
-

**SuperVOOC 2.0 (2019-2020)**

- 65W
- / **10V 6.5A**
- OPPO Find X Reno

**125W / 240W (2021-)**

OPPO - **125W** 10V 12.5A - **240W** 24V 10A

[!WARNING] VOOC OPPO Type-C VOOC

## 6.2.6 FCP / SCP

**FCP (Fast Charge Protocol, 2015)**

- 18W
- 9V / 12V
- 2A
- D+/D-
-

**SCP (SuperCharge Protocol, 2016)**

SCP VOOC

-
- SCP 1.0 22.5W (5V 4.5A 4.5V 5A)
- SCP 2.0 40W (10V 4A )
- SCP 3.0 66W (11V 6A)
-
-
-
-
- FCP

[!NOTE] FCP SCP SCP FCP FCP FCP SCP

## 6.2.7 Pump Express (PE / PE+)

**Pump Express Plus (PE+, 2015)**

- 18-24W
- 5V - 12V
-
- D+/D-
-
-
- QC

**Pump Express 3.0 (PE 3.0, 2017)**

- 30W
- 3V - 6V
- **USB Type-C** Type-C
- 20 70%

USB PD PE

## 6.2.8 vivo FlashCharge

vivo " "

**(2016)**

- 22.5W
- / 9V 2.5A 5V 4.5A
-

**FlashCharge 2.0**

- 44W 55W 66W 120W 200W
-
- vivo

---

## 6.2.9

USB PD

**(Mi Turbo Charge)**

**QC 3.0 (2016-2017)** - 18W (9V 2A / 12V 1.5A) - QC 3.0 - 5 Note 2 -

**27W (2018)** - 27W (9V 3A) - QC 4/QC 4+ USB PD - MIX 2S 8 - QC PD

**(2019-2020)**

**33W** - 33W (11V 3A) - - - - - 9 Pro Redmi K20 Pro

**50W** - 50W (10V 5A) - + USB PD - 25W - 10 Ultra

**67W** - 67W (11V 6.1A 20V 3.35A) - - 11V 6.1A - **USB PD** 20V 3.35A - - 2250mAh - 33.5W - 11 Redmi K40 Pro

**(2021-)**

**120W** - 120W (20V 6A 12V 10A) - - 12V 10A - **PD** 20V 6A - **+** - 2500mAh - MTW - 15 4500mAh - 11 Pro/Ultra 12 Pro

**210W** (2023) - **210W** (20V 10.5A) - - **100W** + - **15C** 2-3C - **MTW** - 4 50% **9** 4900mAh - Redmi Note 12

- -**USB PD** iPhone MacBook - **QC** QC 3.0/4+

/

```
graph LR
    A[   <br/>120W] --> B[USB-C   ]
    B --> C[     1<br/>60W]
    B --> D[     2<br/>60W]
    C --> E[   1<br/>2500mAh]
    D --> F[   2<br/>2500mAh]

    style A fill:#ffe1e1
    style C fill:#e1f5ff
    style D fill:#e1f5ff
    style E fill:#e1ffe1
    style F fill:#e1ffe1
```

- **34** - - 80%

| | | PD | QC |
|---|---|---|---|
| 120W | 120W | 65W PD | 18W QC 3.0 |
| 67W | 67W | 45W PD | 18W QC 3.0 |
| PD | 27W-45W PD | PD | QC |

[!TIP]

[!NOTE] 67W USB PD

## 6.2.10 (mCharge)

- 18W 24W 36W
- QC
-

## 6.2.11 AFC (Adaptive Fast Charging)

- 15W 18W
- 9V
- 1.67A (15W) 2A (18W)
- D+/D-
- QC 2.0 9V

[!TIP] **USB PD + PPS** AFC

# 6.3

| | | | | |
|---|---|---|---|---|
| QC 2.0/3.0 | 18W | | | |
| QC 4+ | 100W | USB PD | | PD |
| VOOC/SuperVOOC | 20-240W | | OPPO/OnePlus/realme | |
| FCP | 18W | | / | |
| SCP | 22.5-66W | | / | |
| PE/PE+ | 18-24W | | | MTK |
| AFC | 15-18W | | | QC |

## 6.4

### 6.4.1

- 
- 5V 1A/2A
- 
- QC 2.0/3.0 9V
- QC + FCP

### 6.4.2

- **VOOC**
- 
- 

### 6.4.3 USB PD

[!IMPORTANT] USB PD 3.0 **PPS** Type-C

- QC 4+ USB PD - PD - PD + PPS - **OPPO/** PD

### 6.4.4

1. 
2. 
3. **USB PD** USB PD
4. 

## 6.5 USB PD (Power Delivery)

USB PD **USB-IF** Type-C

### 6.5.1 USB PD

- ❌
- ❌
- ❌
- ❌

USB PD

### 6.5.2 USB PD

D+/D- USB PD **CC** Configuration Channel

#### CC

Type-C CC CC1 CC2

1. Type-C
2. Source Sink
3. CC
4. **PD**

#### PD

```
sequenceDiagram
    participant C as    <br/>(Source)
    participant D as   <br/>(Sink)

    Note over C,D:
    C->>D: 1.      (CC   )
    C->>D: 2.      5V

    Note over C,D:
    C->>D: 3. Source_Capabilities<br/>(       )
    Note right of D:   : 5V/3A, 9V/3A,<br/>15V/3A, 20V/5A

    D->>C: 4. Request<br/>(    20V 3A)

    C->>D: 5. Accept<br/>(  )

    Note over C,D:
    C->>D: 6. PS_RDY<br/>(    )
    C->>D: 7.    20V 3A

    Note over C,D:
    D->>C:          Request<br/>
```

1. Type-C CC
2. 5V
3. `Source_Capabilities` /
4. `Request`
5. `Accept` `Reject`
6. `PS_RDY` Power Supply Ready
7.

[!IMPORTANT] USB PD " " D+/D- " " PD

## 6.5.3 PD

USB PD CC

| | | |
|---|---|---|
| **Source_Capabilities** | Source → Sink | |
| **Request** | Sink → Source | |
| **Accept** | Source → Sink | |
| **Reject** | Source → Sink | |
| **PS_RDY** | Source → Sink | |
| **Get_Sink_Cap** | Source → Sink | |
| **Soft_Reset** | Both | PD |
| **Hard_Reset** | Both | 5V |

## 6.5.4

**PD 2.0 / 3.0 (2016-2018)**

- **100W** (20V 5A)
- 
- 5V
- 9V 12V 15V 20V
- 5A E-Marker
- 

- **45W** 5V/3A, 9V/3A, 15V/3A, 20V/2.25A - **65W** 5V/3A, 9V/3A, 15V/3A, 20V/3.25A - **100W** 5V/3A, 9V/3A, 15V/3A, 20V/5A

**PD 3.1 (2021)**

- **240W** (48V 5A)
- **EPR (Extended Power Range)**
- 28V 36V **48V**
- 
- **EPR**

## 6.5.5 PPS (Programmable Power Supply)

PPS **USB PD 3.0**

**PPS**

PD 5V 9V 15V 20V - 9V 4.2V - 9V → 4.2V -

**PPS**

- 3.3V - 21V PD 3.0 PPS
- **20mV** 0.02V
-

```
graph LR
    A[   PD<br/>9V   ] -->|     | B[4.2V   ]
    C[PPS<br/>4.2V   ] -->|     | D[4.2V   ]

    style A fill:#ffe1e1
    style B fill:#fff4e1
    style C fill:#e1ffe1
    style D fill:#e1ffe1

    Note1[   <br/>   ]
    Note2[   <br/>   ]
```

**PPS**

- ⚡
- 🌡️
- 🔋 5-10%
- 📱

**PPS**

PPS

| | | **PPS** |
|---|---|---|
| 0-30% | 3.6V | 3.8V |
| 30-70% | 3.9V | 4.1V |
| 70-90% | 4.1V | 4.3V |
| 90-100% | 4.3V | 4.4V |

[!NOTE] " 2.0" "PD " PPS iPhone 15 Pro PPS

---

## 6.5.6 USB PD vs

| | **USB PD** | |
|---|---|---|
| | ✅ USB-IF | ❌ |
| | ✅ | ❌ |
| | CC | D+/D- / |
| | | " " |
| | 240W (PD 3.1) | 240W (OPPO) |
| | ✅ PPS 20mV | QC 3.0 200mV |
| | ✅ | |
| | ✅ | ❌ |
| | ✅ | ⚠️ |

**PD**

1. 2024 USB-C
2. PPS PD
3. PD
4.

[!IMPORTANT] OPPO **USB PD** " " " "

## 6.6 (E-Marker )

Type-C

- **3A** C-to-C 60W (20V 3A)
- **5A** **E-Marker** “ 5A ” 100W (20V 5A)
- **EPR** PD 3.1 240W

### 6.6.1 E-Marker

```
graph LR
    A[   ] -->|CC     | B[  <br/>E-Marker   ]
    B -->|      | C[  ]

    B --> D[      :<br/>1.        5A<br/>2.     <br/>3.      <br/>4.     ]

    style A fill:#ffe1e1
    style B fill:#e1f5ff
    style C fill:#e1ffe1
    style D fill:#fff4e1
```

[!WARNING] 3A 100W 60W

# 6.7

## 6.7.1 1

| | | | | | |
|---|---|---|---|---|---|
| 66W (SCP) | Mate 40 Pro | 66W | 65W | SCP | ✅ |
| 66W (SCP) | 11 | 66W | 27W | USB PD | ⚠️ PD |
| 66W (SCP) | iPhone 14 Pro | 66W | 27W | USB PD | ⚠️ PD iPhone |
| OPPO 65W (VOOC) | OPPO Find X5 Pro | 65W | 65W | SuperVOOC | ✅ |
| OPPO 65W (VOOC) | 11 | 65W | 10W | | ❌ |
| OPPO 65W (VOOC) | iPhone 14 Pro | 65W | 0W | | ❌ VOOC PD |
| 120W | 12 Pro | 120W | 120W | | ✅ |
| 120W | iPhone 14 Pro | 120W | 27W | USB PD | ✅ PD iPhone |
| 120W | MacBook Pro 14 | 120W | 96W | USB PD | ✅ PD |
| 140W (PD) | MacBook Pro 16 | 140W | 140W | USB PD 3.1 | ✅ |
| 140W (PD) | 12 Pro | 140W | 67W | USB PD | ✅ PD |
| 140W (PD) | Mate 40 Pro | 140W | 27W | USB PD | ✅ PD SCP |

✅ **USB PD** ✅ - ⚠️ + PD - SCP ❌PD - **OPPO** VOOC

## 6.7.2 2

11 Pro (67W ) + 67W

| | | | **0-50%** |
|---|---|---|---|
| 6A | 67W | 15 | ✅ |
| 5A E-Marker | 60W | 17 | ⚠️ |
| 3A | 18W | 45 | ❌ |
| | 10W | 70 | ❌ |
| 1 | 67W | 15 | ✅ |
| 3 | 25W | 35 | ⚠️ |

- - - - >60W 5A/6A

### 6.7.3 3

**1** **PD** - Anker - 100W / 140W USB-C PD - USB PD 3.0/3.1 + PPS + QC 4+ - Switch -

**2** **GaN** - Anker - 100W / 120W 2C1A / 3C1A - USB PD 3.0 + PPS + QC 3.0/4+ - - Anker 747 (150W) - 100W (C1) / 100W (C2) - 100W + 50W - 65W + 45W + 40W

**3** - Baseus Ugreen - 200W+ 4-6 - -

[!TIP] **GaN** 100W GaN 1/3

## 6.8

### 6.8.1

| | USB BC 1.2 | USB PD |
|---|---|---|
| **(OVP)** | 5-10V | + |
| **(OCP)** | MCU | CC |
| **(OTP)** | / | |
| **(SCP)** | | |
| | BMS + | BMS + PD |
| | | E-Marker |
| | | PS_RDY |
| | | Role Swap |

### 6.8.2

1.
2. USB-IF
3. USB-IF
4. " "
5.
6. /
7. >50°C
8. VOOC/SuperVOOC
9.
10. 100%
11. 80-90% " "
12.
13. <0°C >40°C
14.
15.

16.

17.

## 6.9

| | | | | |
|---|---|---|---|---|
| **USB-IF** | USB Implementers Forum | USB | USB | |
| **D+/D-** | Data Plus / Data Minus | USB | | |
| **CC** | Configuration Channel | Type-C | PD | |
| **E-Marker** | Electronically Marked Cable | | | |
| **MCU** | Microcontroller Unit | | | |
| **BMS** | Battery Management System | | | |
| | Direct Charging | | | |
| | Dual-Cell Battery | | | |
| | Multi-Tab | | | |
| | Handshake Protocol | | | |
| **GaN** | Gallium Nitride | | | |
| **PPS** | Programmable Power Supply | PD 3.0 | 20mV | |
| **EPR** | Extended Power Range | PD 3.1 | 28V-48V | 240W |
| **OVP** | Over Voltage Protection | | | |
| **OCP** | Over Current Protection | | | |
| **OTP** | Over Temperature Protection | | | |
| **SCP** | Short Circuit Protection | | SuperCharge Protocol | |
| **C-to-C** | USB-C to USB-C | Type-C | Type-C | |
| **A-to-C** | USB-A to USB-C | USB-A | Type-C | |

## 6.10

### 6.10.1

- USB Power Delivery Specification (USB-IF )
- USB Type-C® Cable and Connector Specification
- Qualcomm Quick Charge

### 6.10.2

- **POWER-Z** USB
- **ChargerLAB KT002** PD
-

## 6.10.3

- USB-IF

[!NOTE] 2023 USB-IF

# 7. 6 (FAQ & Common Misconceptions)

, , ,

## 7.1 📑

- 
- 
- 
- Thunderbolt
- 
- 
- 
- 

## 7.2

### 7.2.1 Q1: Type-C ?

**A**: !

Type-C ( ), :

| | | | | | |
|---|---|---|---|---|---|
| | ❌ | 5-15W | ❌ | ¥10-20 | |
| **USB 2.0** | 480 Mbps | 15W | ❌ | ¥20-40 | |
| **USB 3.2 Gen 1** | 5 Gbps | 60W | ❌ | ¥40-80 | |
| **USB 3.2 Gen 2** | 10 Gbps | 100W | ⚠️ | ¥80-150 | + |
| **USB-C** | 10-20 Gbps | 100W | ✅ 4K | ¥100-200 | |
| **Thunderbolt 4** | 40 Gbps | 100W | ✅ 8K | ¥200-500 | |

: 1. ⚡(SS 5A ) 2. 3. USB 4. ,

[!WARNING] !¥10 ¥500 , "Type-C"

### 7.2.2 Q2: Type-C USB-C ?

**A**: , : - **Type-C**: USB-IF - **USB-C**:

: 24 USB

: Type-C/USB-C ≠ ≠

- Type-C
- (USB 2.0 USB 3.x USB4 Thunderbolt)

---

### 7.2.3 Q3: Thunderbolt USB-C ?

**A**:

- **USB-C/Type-C**: ( )
- **Thunderbolt**: ( )

: - Thunderbolt 3/4/5 Type-C - Type-C Thunderbolt -⚡Thunderbolt - USB-C

```
graph TB
    A[Type-C   ] --> B{    }
    B --> C[USB 2.0\u003cbr\u003e480 Mbps]
    B --> D[USB 3.2\u003cbr\u003e10-20 Gbps]
    B --> E[USB4\u003cbr\u003e20-40 Gbps]
    B --> F[Thunderbolt 3/4\u003cbr\u003e40 Gbps]
    B --> G[Thunderbolt 5\u003cbr\u003e80-120 Gbps]

    style A fill:#fff4e1
    style C fill:#ffe1e1
    style D fill:#fffacd
    style E fill:#e1ffe1
    style F fill:#e1f5ff
    style G fill:#ffe1ff
```

: ⚡

---

### 7.2.4 Q4: Type-C ?

:

1. - Thunderbolt, USB-C - :
2. - ( ) - - :
3. - **Windows**: USB/Thunderbolt - **Mac**: - :
4. - ( eGPU) - :
5. - Thunderbolt - : , Thunderbolt

:

---

### 7.2.5 Q5: USB Type-A ?

**A**: ,

**Type-A** : - ✅ : ✅, - : ⚠️U - : (>15W) (>20Gbps)

: - : Type-C( Type-C) - : Type-A( ) - : Type-C, - : Type-A ,

[!NOTE] 2024 Type-C ( ),

---

### 7.2.6 Q6: Mini USB Micro USB ? ?

**A**: , **Type-C**

| | **Mini USB** | **Micro USB** | |
|---|---|---|---|
| | 2000 | 2007 | - |
| | (7×3mm) | (7×1.8mm) | - |
| | 5,000 | 10,000 | - |
| | 480 Mbps (USB 2.0) | 480 Mbps (USB 2.0) | - |
| | MP3 | | - |
| | | | Type-C |

: ! **Type-C**

## 7.3

### 7.3.1 Q7: USB 3.0 U ?

:

**1. USB 2.0**

| | | |
|---|---|---|
| 30-40 MB/s | (USB 2.0) | (USB 3.0) |
| 30-40 MB/s | USB 2.0 | USB 3.0 |

**2. U** - : USB 3.0 , 50-100 MB/s - : U - : U ( )

**3.** - : , - : - : (ZIP/RAR),

**4.** - : " " - : USB 3.0 - :

**5. USB** - : 3m+ , - : - : ≤1.5m , ( )

### 7.3.2 Q8: USB 3.2 Gen 2x2 Type-C ?

**A**: , **Type-C**

: - USB 3.2 Gen 2x2 (2 TX/RX ) - Type-A **1** TX/RX, - Type-C 24 2

:

| **USB** | | **Type-A** | **Type-C** |
|---|---|---|---|
| USB 3.0 (Gen 1) | 5 Gbps | ✅ | ✅ |
| USB 3.1 Gen 2 | 10 Gbps | ✅ | ✅ |
| **USB 3.2 Gen 2x2** | 20 Gbps | ❌ | ✅ |
| USB4 | 40 Gbps | ❌ | ✅ |

### 7.3.3 Q9: USB4 Thunderbolt 4 ?

**A**: **Thunderbolt 4 USB4 " "**

:

| | USB4 | Thunderbolt 4 |
|---|---|---|
| | 20 Gbps( 40) | **40 Gbps** |
| **PCIe** | (0-32G) | **32 Gbps** |
| | | **2×4K** |
| **DMA** | | **VT-d** |
| | | |
| | | |

: - **eGPU** → Thunderbolt 4 - → USB4 - **USB** → USB 3.2

: 4 Thunderbolt vs USB4

---

### 7.3.4 Q10: USB 3.0 USB 2.0, ?

**A**: ,

:

```
graph LR
    A[USB 3.0   ] --> B{   }
    B --> C[USB 3.0   \u003cbr\u00✅      5 Gbps]
    B --> D[USB 2.0   \u003cbr\u003⚠️      480 Mbps]

    E[USB 2.0   ] --> F{   }
    F --> G[USB 3.0   \u003cbr\u003⚠️      480 Mbps]
    F --> H[USB 2.0   \u003cbr\u00✅      480 Mbps]

    style C fill:#e1ffe1
    style D fill:#ffe1e1
    style G fill:#fffacd
    style H fill:#e1f5ff
```

:

| | | | |
|---|---|---|---|
| USB 3.0 | USB 3.0 | USB 3.0 | 5 Gbps ✅ |
| USB 3.0 | USB 2.0 | USB 3.0 | 480 Mbps ⚠️ |
| USB 3.0 | USB 3.0 | USB 2.0 | 480 Mbps ⚠️ |
| USB 2.0 U | USB 3.0 | USB 3.0 | 480 Mbps ⚠️ |

[!IMPORTANT] ! USB 3.0, USB 2.0

---

## 7.4

### 7.4.1 Q11: Type-C ?

:

**1.**

| | | |
|---|---|---|
| 3A | 15W (5V 3A) | 5A E-Marker |
| 5A E-Marker | 100W (20V 5A) | ✅ |
| ( ) | 5-10W | , |

**2.** - : PD, VOOC, - : 5-10W( ) - : ,

**3.** / - : 🔧 🌬️: ⚠️ - : - ( ) - - ,

**4.** - : 5V 1A - : 5W - : (18W+)

**5.** - : , - : / > - :

---

## 7.4.2 Q12: 65W ?

**A**: ,

**USB PD** :

```
sequenceDiagram
    participant C as 65W PD
    participant P as

    C->>P: 1.   ,       :\u003cbr\u003e5V/3A, 9V/3A, 15V/3A, 20V/3.25A
    P->>C: 2.    9V 2A (18W)
    C->>P: 3.   ,   9V 2A

    Note over C,P:          65W\u003cbr\u003e
```

: - ✅ : ✅" - : PD, 5✅1-2A - : ✅ - :

:

| | | | | |
|---|---|---|---|---|
| 65W PD | iPhone 14 Pro | 27W | iPhone | 27W |
| 65W PD | 11 | 27-45W | PD | |
| 65W PD | AirPods | 5W | , | |
| 65W PD | MacBook Air | 65W | ✅ | |

[!TIP] : , **65-100W** **PD** , ,

---

## 7.4.3 Q13: "100W", ?

:

**1.**

: Anker 100W 3

| | C1 | C2 | A | | |
|---|---|---|---|---|---|
| C1 | 100W | - | - | ✅ | |
| C1 + C2 | 65W | 30W | - | ⚠️ | |
| C1 + C2 + A | 45W | 30W | 18W | ⚠️ | 100W |

**2.** - 3A 100W : 60W (20V 3A) - : **5A E-Marker**

**3.** - 100W, 65W - : 65W

**4. PD** - : 5V 9V 15V 20V - : 12V( ) - : 9V,

[!WARNING] **"100W"** , **100W** ,

---

### 7.4.4 Q14: Type-C ?

:

**1.** - OPPO VOOC VOOC, USB PD - : 5V 1A - : USB PD

**2. C to C** - C to C , E-Marker - , - :

**3.** - CC - - :

**4.** - Type-C , - : , ( )

---

## 7.5 Thunderbolt

### 7.5.1 Q15: Type-C , Thunderbolt ?

**A**: , Thunderbolt

:

**1.** - ✅ ⚡ = Thunderbolt - = USB-C

**2.**

**macOS**:

```
Apple → → → Thunderbolt
```

**Windows**:

```
→ → "Thunderbolt Controller"
```

**3.**

| | Thunderbolt | | |
|---|---|---|---|
| **Thunderbolt 4** | TB4/TB3 | ✅ | |
| **Thunderbolt 3** | TB4/TB3 | ✅ | TB3 |
| **USB4** | TB | ⚠️ | PCIe |
| **USB 3.2** | TB | ⚠️ | USB , TB |

[!IMPORTANT] **eGPU** **Thunderbolt** USB-C

---

## 7.5.2 Q16: Thunderbolt , ?

**6** :

**1:** - ⚡ - /

**2:** - Thunderbolt⚡ ( ) - - ( ≤0.8m, ≤2m)

**3:**

**Windows**: - Intel Thunderbolt Software -

**Mac**: - macOS

**4: BIOS**

**Windows PC**: - BIOS( F2/Del) - Thunderbolt - "Thunderbolt Support" - "Thunderbolt Boot Support"( )

**5:**

**Windows 10/11**: - → → Thunderbolt - Thunderbolt

**Mac**: - → → Thunderbolt - " "

**6:** - (Thunderbolt ) - eGPU

: ,

---

## 7.5.3 Q17: Thunderbolt ? ?

**A**: ,

**Thunderbolt** :

| | | |
|---|---|---|
| | >0.8m | +¥100-300 |
| **E-Marker** | | +¥30-50 |
| | , | +¥20-50 |
| | , | +¥30-80 |
| **Intel** | | +¥50-100 |

: - ✅ ( charging <60✅) - ✅SB ( ) - (<0.5m)

**Thunderbolt** : - ❌ 40 Gbps ❌ - eGPU ❌ ❌ ❌ 100W - (>1m)

[!CAUTION] **¥20** **¥20000** **eGPU** ! ,

## 7.6

### 7.6.1 Q18: ,"SS" "SS 10" "5A" "E-Marker" ?

**A**:

:

| | | |
|---|---|---|
| | USB 2.0 | 480 Mbps |
| **SS** | SuperSpeed | 5 Gbps (USB 3.0) |
| **SS 10 SS+** | SuperSpeed 10 | 10 Gbps (USB 3.1 Gen 2) |
| **SS 20** | SuperSpeed 20 | 20 Gbps (USB 3.2 Gen 2x2) |
| **USB4 40** | USB4 | 40 Gbps |
| ⚡ **Thunderbolt** | | 40-120 Gbps |

:

| | | | |
|---|---|---|---|
| **3A** | 3A | 60W (20V 3A) | |
| **5A 50** | 5A | 100W (20V 5A) | , **E-Marker** |
| **EPR** | 5A | 240W (48V 5A) | (PD 3.1) |

**E-Marker** : - : ( ) - : 5A USB 3.x/4 E-Marker - : "5A" "E-Marker "

: - ✅ : "✅" - : "SS ✅" "SS 20" - : "USB-IF " "Thunderbolt "

### 7.6.2 Q19: ?

**A**: ,

:

| | | | |
|---|---|---|---|
| | 5A PD | ¥30-60 | |
| **U** | USB 3.0 | ¥20-40 | USB 3.0 |
| **SSD** | USB 3.2 Gen 2 | ¥60-120 | 10 Gbps 4K |
| | USB-C | ¥80-150 | + + |
| **eGPU** | Thunderbolt 4 | ¥200-500 | , |

: - ❌ " ❌ " → ✅ " " → - " " →

: 1. ( / / /Thunderbolt) 2. 3. ( ) 4. (USB-IF Thunderbolt )

[!TIP] : ¥50-100 USB 3.2 Gen 2(10 Gbps)+5A , 95%

---

### 7.6.3 Q20: / SSD?

:

| | | | | | |
|---|---|---|---|---|---|
| | | | | **(1TB)** | |
| | HDD | USB 3.0 | ~150 MB/s | ¥300-500 | Elements |
| | SATA SSD | USB 3.1 Gen 2 | ~500 MB/s | ¥500-800 | T5 Extreme |
| **4K** | NVMe SSD | USB 3.2/USB4 | 1000-2000 MB/s | ¥800-1500 | T7 OWC Envoy |
| **8K/** | NVMe SSD | Thunderbolt 4 | 2000-3000 MB/s | ¥1500-3000 | OWC Envoy Pro Acasis |

:

1. **vs** - 512GB: - **1TB**: ( ) - 2TB: , - 4TB+: ,
2. - / : HDD SATA SSD - : NVMe SSD( ≥1000 MB/s) - : Thunderbolt SSD
3. - ✅ **SSD**: ⚠️, - **HDD**: ,
4. - : ⚠️WC - : aigo - ( )

---

## 7.7

### 7.7.1 1: Type-C = +

❌ : Type-C ,

✅ : Type-C , : - Type-C USB 2.0(480 Mbps) - 5W(5V 1A)

: iPhone 15 - : Ty✅-C - : **480 Mbps**(USB 2.0)❌ - iPhone 14 Pro(Lightning) !

: /

---

### 7.7.2 2: USB 3.0

❌ : USB

✅ : , ⚠️ : - ⚠️ USB 3.0 - USB 2.0

: 1. / 2. / 3.

---

### 7.7.3 3: Thunderbolt 3

❌ : "Thunderbolt 3"

✅ : Thunderbolt 3 :

| | PCIe | 4K |
|---|---|---|
| **Alpine Ridge** | 16 Gbps | |
| **Titan Ridge** | **32 Gbps** | |

: - eGPU: Titan Ridge **20-30%** - : **Thunderbolt 4**( 32 Gbps)

---

### 7.7.4 4: ,

❌ : 100W " "

✅ : , :

| | | **100W** |
|---|---|---|
| iPhone 14 Pro | 27W | **27W**( ) |
| 11 | 55W( ) | 27W(PD ) |
| MacBook Air | 30W | 30W |
| MacBook Pro 16 | 96W | 96W |

: ,

---

### 7.7.5 5:

❌ : " "

✅ : : - : - : ,

: 1. ✅ (USB-IF Thunderb✅) 2. (✅ SS 10 ) 3. (Ank❌ Belkin Apple ) 4.

---

### 7.7.6 6: USB PD " "

❌ :

✅ : USB PD : - : " " - : - : - :

: 140W MacBook Pro iPhone - : 140W - iPhone : 9V 3A (27W) - :**27W**( )

: PD

---

### 7.7.7 7: Thunderbolt 4 Thunderbolt 3

❌ : TB4 TB3

✅ : , 40 Gbps

**TB4** : - : TB3 16G PCIe,TB4 32G - : - : 2×4K DMA

: - TB4 " ", " " - , TB4( )

---

# 7.8

## 7.8.1 USB

```
graph TB
    A[USB       ] --> B{      }

    B -->|    | C[    \u003cbr\u003e      ]
    B -->|    | D{      }

    D -->|    | E[    ]
    D -->|    | F{      }

    F -->|    | G[    \u003cbr\u003e   ]
    F -->|    | H{    }

    H -->|    | I[    :\u003cbr\u003e- Windows:      \u003cbr\u003e- Mac:     ]
    H -->|    | J{    }

    J -->|    | K[       Hub\u003cbr\u003e        ]
    J -->|    | L{    }

    L -->|      | M[  :\u003cbr\u003e- Windows: Thunderbolt     \u003cbr\u003e- Mac:     ]
    L -->|    | N[      \u003cbr\u003e    ]

    style A fill:#ffe1e1
    style C fill:#e1ffe1
    style E fill:#e1ffe1
    style G fill:#fffacd
    style I fill:#e1ffe1
    style K fill:#e1ffe1
    style M fill:#e1ffe1
    style N fill:#ffe1e1
```

## 7.8.2

:

| | |
|---|---|
| 1 | 5A E-Marker |
| 2 | |
| 3 | PD / |
| 4 | |
| 5 | |
| 6 | , |

## 7.8.3

:

1. - (U ) - CrystalDiskMark
2. - Windows: → - Mac: → USB
3. - (SS SS 10) -
4. - ( ): - ( ): ( )
5. - - -

# 7.9

## 7.9.1 USB

| | | | | |
|---|---|---|---|---|
| | | | **10GB** | |
| USB 2.0 | High Speed | 480 Mbps | ~5 | Type-A/B/C |
| USB 3.0 | SuperSpeed | 5 Gbps | ~30 | Type-A/B/C |
| USB 3.1 Gen 2 | SuperSpeed 10 | 10 Gbps | ~12 | Type-A/C |
| USB 3.2 Gen 2x2 | SuperSpeed 20 | 20 Gbps | ~6 | **Type-C** |
| USB4 | - | 40 Gbps | ~3 | **Type-C** |
| Thunderbolt 3/4 | - | 40 Gbps | ~3 | **Type-C** |
| Thunderbolt 5 | - | 120 Gbps | ~1 | **Type-C** |

## 7.9.2 USB

| | | | | |
|---|---|---|---|---|
| USB 2.0 | 5V | 0.5A | **2.5W** | |
| USB 3.0 | 5V | 0.9A | **4.5W** | |
| USB BC 1.2 | 5V | 1.5A | **7.5W** | |
| USB PD | 5-20V | 5A | **100W** | / |
| USB PD 3.1 EPR | 5-48V | 5A | **240W** | / |

## 7.9.3

| | **Type-A** | **Type-C USB 2.0** | **Type-C USB 3.x** | **USB4** | **Thunderbolt** |
|---|---|---|---|---|---|
| **Type-A (USB 2.0)** | ✅ 480M | ✅ 480M | ✅ 480M | ✅ | ✅ |
| **Type-A (USB 3.x)** | ✅ | ✅ 480M | ✅ | ✅ | ✅ |
| **Type-C (USB 2.0)** | ⚠️ | ✅ 480M | ✅ | ✅ | ✅ |
| **Type-C (USB 3.x)** | ⚠️ | ✅ 480M | ✅ | ✅ | ✅ |
| **USB4** | ⚠️ | ✅ 480M | ✅ | ✅ | ⚠️ |
| **Thunderbolt 4** | ⚠️ | ✅ 480M | ✅ | ✅ | ✅ |

✅ ⚠️ ❌ |

### 7.9.4

:

| | | | |
|---|---|---|---|
| **CrystalDiskMark** | Windows | /U | |
| **ATTO Disk Benchmark** | Win/Mac | | |
| **POWER-Z KT002** | | USB / | ¥300-500 |
| **USB Device Tree Viewer** | Windows | USB | |
| **System Information** | macOS | USB/TB | |

: - USB-IF - Thunderbolt

: - USB-IF - Thunderbolt - USB PD

## 7.10

USB Thunderbolt , :

✅
✅
✅
✅

, : 1. FAQ 2. 3.

: - 2 : USB - 3 : USB - 4 : Thunderbolt - 5 :